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Probable changes in the mix of materials used to manufacture automobiles were examined to determine if economic or technical problems in recycling could arise such that the "abandoned automobile problem" would be resurrected. Future trends in materials composition of the automobile were quantified, and possible constraints related to material characteristics, availability, and price were examined. The automobile resource recovery industry was studied in terms of economic incentives for recycling and technical obstacles to recycling of deregistered automobiles. A macromodel of the economy, the EPA sponsored SEAS model, was used to study overall economic and environmental effects and to bring to light any secondary effects that might be important.

The major conclusions are that auto hulks are likely to be in great demand for recycling, that the backlog of abandoned cars in the environment will very likely disappear by the early 1980's and that changes in materials composition of autos will accentuate this tendency. Vertical integration of the larger firms in the industry is a likely trend at both the input (hulk collection, dismantling, and preparation for shredding) and output (non-ferrous metals smelting) ends of the central hulk processing (shredding) part of the business. Overall economic impacts of the various automobile materials composition scenarios we studied were rather small, although effects in particular industries, relative to a base-case, no-change in materials composition scenario, were noticeable.

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IMPACTS OF MATERIAL SUBSTITUTION IN AUTOMOBILE MANUFACTURE ON RESOURCE RECOVERY - Volume I: Results and Summary

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PREFACE

The work reported here was undertaken by IR&T for the Environmental Protection Agency under Contract 68-01-3142. The first volume is a self-contained exposition of our investigations, the results we obtained, and our conclusions. Volumes II, III and IV contain as appendices working papers on various subtopics pertinent to the main topic that were prepared during the course of our study. They contain additional detail and data which supplement the presentation in Volume I. The appendices should be consulted for methodological details and for data which underlie some of the results presented in Volume I.

The EPA project monitors for the study were Mr. Ted Williams and, after Mr. Williams' transfer from EPA to the Commerce Department, Mr. Calvin Lawrence. The Office of Solid Waste, Environmental Protection Agency, provided financial support.

SECTION I

STUDY BACKGROUND AND SUMMARY

Resource recovery from automobiles has received a great deal of attention in recent years. In the decade preceding 1974, the impetus was the recognition that large numbers of retired autos were being deposited in the environment to slowly decompose. They presented an environmental problem in that they became ubiquitous eyesores and added to the load of waste a consumption oriented society was depositing on its surroundings. Between 1964 and 1974, at least six major studies [1-6] were made of the "abandoned automobile problem." Many of these studies were concerned with government policy alternatives to encourage recycling of automobiles, and to discourage abandonment of autos in the public domain. At present, the problem appears to be ameliorating, at least in the short run. Recent high scrap prices and the rapid expansion of automobile shredder capacity have apparently stopped the buildup of the inventory of retired autos in and out of junk yards.* Pressure for governmental action by regulation has abated, and attention is directed increasingly toward the economic aspects; i.e., to the need to regard junk automobiles as valuable raw material resources.

The increased urgency level of the "abandoned automobile problem" in the 1960s had its source in a series of industrial events, well recognized in hindsight, and its amelioration is apparently due to some natural responses to these events. The shift in the 1950's and 1960's by the steel industry from the open-hearth method of production to the basic-oxygen-furnace process caused a decrease in the amount of scrap required per unit of steel output, and upgraded the quality requirements on acceptable scrap. Recycled automobile hulks processed

*The Commodity Data Summaries, 1975, publication of the Bureau of Mines contains the following statement in its section on iron and steel scrap (pp 84-85): "The high price of scrap has also resulted in removal and recycling of many derelict automobile hulks that formerly disfigured the landscape."

into so-called "#2 bundles," rank very low on the scale of scrap quality and were the first source of scrap to be impacted by this decreased demand. Auto hulks assumed a negative economic value and prices for #2 bundle scrap produced from automobile hulks were low. At the same time, sales of new automobiles and retirements of old ones were almost doubling between 1958 and 1972. As a consequence, the inventory of unrecycled automobile hulks residing in the environment expanded from about one million in 1958 to some thirteen million in 1970.[4]

The availability of this huge, low-cost raw material resource has eventually evoked some economic and technical responses. The automobile shredder has appeared and upgraded the quality of scrap that can be made from automobile hulks to an acceptable level. Prices for shredder scrap of automotive origin now approximate those obtained for the highest grades of obsolete scrap. Shredder capacity has increased almost fourfold from 1966 to 1975.

The diminished use of scrap by the major steel producers, and consequent lowering of scrap costs, encouraged the growth of a regional steel industry based on the electric furnace which uses 95% to 100% scrap charge. Production by electric steel-making furnaces increased from 8.4 million tons in 1960 to 20.2 million tons in 1970, and is expected to almost triple that amount by 1985.

The study reported here was undertaken by International Research and Technology, Inc. for the Environmental Protection Agency to focus on a particular aspect of resource recovery from automobiles; namely, the long-range technical, environmental, and economic consequences of changes in the materials input into the manufacture of automobiles. That radical changes in automobile materials consumption are taking place, and will continue, is readily apparent; cars are becoming smaller and lighter and major efforts are being made to improve their fuel economy; lighter weight materials, particularly aluminum and plastics, are being emphasized as replacement for traditional materials. These

changes are being forced by the demands of consumers, and while an industry as large as the domestic automobile industry is limited in its speed of response to changing market demands, there is no doubt that changes will be necessary for as long as high and increasing gasoline prices continue. A recent report to Congress[7] on fuel economy emphasized the importance of automobile weight in national consumption of gasoline.

We have subdivided our study into four parts as follows:

- A quantification of the trends in automobile material composition in the period from now to the 1980-1990 decade.
- An examination of technological and economic problems associated with materials characteristics, availability, and price which could constrain an evident trend toward the use of lighter metals and plastics in automobiles.
- A study of the automobile recycling industry to determine if the perceived changes in automobile materials composition might either alter economic incentives, or present technical problems in recycling automobiles, such that the "abandoned automobile problem" would be resurrected.
- A study of long-range economic and environmental effects using a macromodel of the U.S. economy, the SEAS* model, developed under the auspices of EPA.

The following sections will discuss our findings in each of these four subject areas. Since the project was an attempt to look into an uncertain and dimly perceived future, we are reluctant to term our thoughts and calculations as "results" or "predictions." The term "perceptions" is perhaps more appropriate. In any event, we summarize them in the following ways:

*Strategic Environmental Assessment System.

- The weight of the average car sold in the U.S. will decrease by 20% in 1980 and by 30% in 1990 from its present value (approximately 3,400 lbs). Weight of aluminum and plastics in cars will increase two to threefold on an absolute and percentage basis, displacing iron and steel primarily but also copper and zinc. The trends are shown in Table 1. The ranges given are uncertainties based partly on the aluminum-plastics competition for market share, and reflected in alternate scenarios we have used in our study. (Sec. II and Appendices A & B)
- Availability and price competition between aluminum and plastics does not appear to be a major consideration for determining materials composition of automobiles. If the cost of energy (manufacturing and embodied) is assumed to be the principal determinant of relative prices for aluminum and plastics, a slight advantage accrues to plastics in scenarios where energy costs rise sharply. (Sec. IV and Appendices E & G)
- Performance and safety considerations have many subtle effects on the choice of materials for automobiles, some favoring substitution of aluminum for steel and some discouraging it. In places where a hard wear surface is required (e.g., cylinder walls), iron or steel might be preferred. For structural members where rigidity, high strength, and compactness are required, (e.g., frame members) aluminum construction may show very little weight savings compared to a high strength alloy steel. The galvanic corrosion potential inherent in steel-aluminum interfaces will require that special care be taken in design and manufacturing. Upgraded crash-worthiness requirements, if implemented, are almost certain to drive car weights upward and lessen the potential for substitution of aluminum and plastic for steel. (Sec. III and Appendices D and I)

TABLE 1

AUTOMOBILE COMPOSITION FOR SELECTED MATERIALS
SALES WEIGHTED AVERAGES INCLUDING IMPORTS

	1975	1980	1990
Vehicle Weight, lbs.	3400	2620-2820	2260-2520
Iron & Steel,* lbs.	2660	1680-1980	1120-1570
" " %	77	64-71	50-62
Aluminum,* lbs.	100	150-320	230-540
" %	3	6-12	10-24
Plastics, lbs.	120	170-250	170-390
" %	4	6-9	8-17
Copper*, lbs.	34	20-30	15
" %	1	1	<1
Zinc*, lbs.	28	12	8
" %	1	<1	<1

*Including alloying elements.

- The economic impact of smaller cars with less ferrous material per car is most likely to be in the direction of increased competition among shredder operators for the available supply of automobile hulks. Essential depletion of the backlog of unprocessed automobile hulks would probably be complete by the early 1980's in any case and the decreased steel content of newer automobiles will tend to accelerate this trend. To meet projected 1985 demands for shredded scrap, shredder operators will have to use supply inputs other than automobile hulks (industrial machinery, appliances) to make up 40 to 60% of their total input by weight. (Sec. V and Appendices F and H)
- Increased use of aluminum in automobiles, together with decreased copper and zinc content, should tend to make the nonferrous metal fraction of shredder output more valuable and easier to process. However, the fraction of aluminum that will flow through the collection, dismantling, and hulk preparation stages to the shredder is uncertain. Easily removed parts (hoods, trunk lids, fenders) of all aluminum alloy construction are likely candidates for removal by auto wreckers for use as a raw material for secondary wrought alloy production. By 1990, the amount of aluminum scrap of automotive origin will encourage expansion of secondary production relative to primary production. Secondary producers are likely to expand their product line from the current casting alloys to include wrought alloys. (Sec. VI)
- One effect of the above factors is likely to be an upstream integration of operations by the larger shredder operators. They may want to assure their source of supply by long-term contracts with auto wreckers or by moving into the business themselves. Some of the larger shredder operators have already integrated downstream nonferrous metals processing steps into their operations, principally secondary zinc and aluminum smelting processes. Upstream integration into the auto wrecking business may be necessary to assure a supply of hulks to their shredders and scrap to their secondary aluminum business. (Secs. V and VI)

- The nonmetallic fraction of shredder output will necessarily increase as the weight of plastics in autos increases. Continued landfill disposal of this fraction is likely to increase shredder operation costs somewhat, and foamed plastic material will require separation and alternate disposal. The best prospect overall appears to be in recovery of the energy content of the nonmetallic waste (by incineration, pyrolysis, or some combination thereof) and landfill of the reduced residue. The practical means of implementing this energy recovery is not at hand but,fortunately, the major impact of the increased flow of plastics to the shredder output pile is several years away, and the potential value of the recoverable energy appears to be in a steady uptrend. (Appendix C)
- The SEAS model was used to analyze the economic and environmental impacts of changing material requirements of automobiles in 1985. Four scenarios were run. Three involved changing composition of the automobile. The other, a base case, assumed the composition of the automobile remained at the 1971 level. All other inputs to the SEAS model remained the same. The economic impact of changed materials composition on the economy, as projected by the SEAS model, is small in the context of the whole economy, but noticeable in terms of some sectors. For example, GNP and employment changed by less than one percent when comparing each of the three scenarios to the base case. The sectors most significantly affected were those directly related to the automobile industry: iron and steel, aluminum, and gasoline production with outputs varying between 10 and 20 percent in each case. Sectors selling to these industries were affected between 2 and 20 percent. All other impacts were negligible. (Sec. VII and Appendix J)

- Impacts on the national environment also were found to be negligible. Pollution is reduced slightly from the base case by less than 2% for the major air and water pollutants. (Sec. VII and Appendix J)

- The total quantity of solid waste generated from manufacturing and consumer activities will not be affected, but its composition will change slightly. Availability of ferrous and aluminum scrap will vary approximately 10% in 1995 when comparing the three scenarios to the base case. Reduced ferrous scrap availability for recycling, particularly from automobiles, will create a tight situation in 1985. Increased recycling from non-automotive sources will be necessary to fill the gap. (Sec. VII and Appendix J)

SECTION II

AUTOMOBILE MATERIAL COMPOSITION IN THE 1980 TO 1990 DECADE

Over the next 25 years, the American automobile will change in many basic ways. A new era in automotive engineering is foreseen in which engineering toward functionalism and conservation will dominate. Smaller and lighter cars appear probable because they consume less fuel and materials resources. Smaller vehicles use less street and storage space, thereby contributing less to congestion in urban areas. It is reasonable to expect that smaller cars will cost less to purchase, maintain,and operate. While many cars will still be needed with passenger accommodations large enough for family transportation, exterior dimensions can be considerably reduced without sacrificing passenger space. The fuel economy of all sizes of automobiles can be improved by weight reduction through optimum materials choice, better aerodynamic design, improvements to engines and power trains, and better tire designs.

Weight reductions due to materials changes in cars will occur from substitution of aluminum and plastics for steel and to a lesser extent for copper and zinc. These are the most important materials for recycling considerations which are likely to show significant changes in usage. Hence, they are emphasized in this study. Other materials; e.g., glass and rubber, remain important but the relative amount used, per car, is not likely to change appreciably.

Historically, use of aluminum and plastics for weight reduction first became popular in trucks. Long distance truck operators began to find tangible economic advantages in vehicle weight reduction in the years following World War II. Trucks began to appear with aluminum frames, bodies, wheels, cabs, bumpers, transmission cases, and fuel tanks. A rule-of-thumb of the 1950's was that a pound of weight saved was worth a dollar premium in purchase price for line-haul applications on the Pacific Coast. Notable examples of fibre glass truck components include the one-piece hood and front fenders of Kenworth trucks and the fibre glass front fenders used by Peterbilt Motors.

A projection of future automobile composition will necessarily involve a number of superimposed assumptions and projections. Therefore, our results are not intended as precision forecasts but are a range of possibilities, given a strong market driven incentive toward reduced vehicle weight and improved fuel economy. We present our forecasts in three scenario versions; namely,a "maximum credible aluminum" automobile, "maximum credible plastics" automobile, and a "most likely materials composition" automobile. We divide automobiles into three size categories and project materials composition for each size individually. A composite automobile is then presented based on estimated relative sales for each size. The projections are made for cars to be sold in 1980 and 1990.

The three size categories of automobiles chosen for this study are:

- Class "A" - Full size family cars, six passengers.
- Class "B" - Compact cars, five passengers.
- Class "C" - Subcompact cars, four passengers.

While these divisions are defined by normal full load capacity in seated adult passengers, it generally follows that other features such as curb weight and engine size are characteristically similar within each category. Table 2 lists some of the parameter ranges that distinguish each car class.

Actual materials composition of recent model automobiles can be only approximately determined, but a fair sampling of recent published data on domestic makes is shown in Tables 3 and 4. Data on some foreign models is shown in Table 5. The "plastics" category includes a wide variety of substances. Table 6 gives a listing by type with estimates from two sources of plastics usage per car in 1974. From this and other data, a nominal baseline materials composition for 1975 models has been constructed as shown in Table 7.

TABLE 2

BASELINE CAR CATEGORIES

	Car "A"	Car "B"	Car "C"
Description	Full Size Family Sedan	Compact	Small or Sub Compact
No. Adult Passengers	6	5	4
Curb Weight, lb	>3,500	2,500-3,500	<2,500
Wheelbase, in	>110	98-110	<98
Total Length, in	>200	180-200	<180
Total Seating Width, in	>100	90-100	75-80
Luggage Space, ft^3	12-20	10-14	6-10
Engines:			
Typical No. Cyl.	8	6	4
Displacement, in^3	>300	200-300	<150
SAE Net HP	>140	95-120	<95
Fuel Economy, mpg*			
Urban	10-13	13-18	18-24
Highway	15-18	18-28	24-38

*By U.S. EPA dynamometer method deduced from EPA, FEA pamphlet, "1974 Gas Mileage Guide for New Car Buyers."

TABLE 3

MATERIALS COMPOSITION OF RECENT U.S. AUTOMOBILES

	USBM Composite 1954-1965		Dodge Dart 1965		Plymouth Belvedere 1965		Chrysler New Yorker 1965		1969 NAAO Composite		1972 two-dr. Sedan	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	-	-	1616	61.2	1956	61.7	2492	58.9	-	-	2175	52.2
Alloy & Stainless Steel	-	-	120	4.5	126	4.0	204	4.7	-	-	380	9.2
Total Steel	2532	70.8	1736	65.7	2082	65.7	2696	63.7	2302	62.2	2555	61.4
Cast Iron, Malleable Iron	511	14.3	402	15.2	456	14.4	605	14.3	518	14.0	712	17.1
Aluminum	51	1.4	33	1.2	77	2.4	72	1.7	55	1.5	108	2.6
Copper, Brass	32	0.9	28	1.1	36	1.1	44	1.0	30	0.8	56	1.4
Rubber	145	4.1	147	5.6	171	5.4	189	4.5	96	2.6	120	2.9
Glass	87	2.4	74	2.8	96	3.0	124	2.9	-	-	100	2.4
Plastic	-	-	16	0.6	18	0.6	33	0.8	54	1.5	190	4.6
Other	216	6.0	205	7.8	230	7.3	468	11.1	645	17.4	320	7.7
Totals[a]	3575		2641		3166		4231		3700		4161	
Reference No.	(8)		(9)		(9)		(9)		(10)		(11)	

(a). Total weights should represent dry curb weight. For actual curb weights with water, oil, and one-half tank fuel, add approximately 100 lb. Percentages may not total 100% in all instances due to numerical round-offs.

TABLE 4

MATERIALS COMPOSITION OF RECENT MODEL PLYMOUTH AUTOMOBILES[12]

	1973	1968	1963
Wheelbase, in	120	116	116
Standard Engine	V-8(318-cu.in.)	V-8(318-cu.in.)	V-8(273-cu.in.)
Transmission	Automatic	Automatic	Automatic
Steering	Power	Manual	Manual
Brakes	Power	Manual	Manual
Heater	Yes	Yes	Yes
Radio	Yes	Yes	Yes
Curb Weight, lb	4014	3415	3355

Material Grouping in Lbs. and Percent

	1973 Wt.,lb	1973 Wt.%	1968 Wt.,lb	1968 Wt.%	1963 Wt.,lb	1963 Wt.%
Cast Iron	482	12.0	394	11.5	473	14.0
Malleable Iron	169	4.2	64	1.9	63	1.9
Plain Carbon Steel	2105	52.4	1914	56.0	1807	53.9
Galvanized Steel	75	1.9	71	2.1	53	1.6
Aluminized Steel	31	0.8	24	0.7	24	0.7
Alloy Steel	95	2.4	121	3.5	121	3.6
Stainless Steel	13	0.3	12	0.4	12	0.4
Aluminum	75	1.9	71	2.1	75	2.2
Magnesium	0	0.0	0	0.0	2	0.1
Zinc	65	1.6	37	1.1	28	0.8
Copper and Copper Base Alloys	26	0.6	38	1.1	36	1.1
Lead	22	0.5	30	0.9	32	1.0
Body Solder	5	0.1	5	0.1	5	0.1
Glass	96	2.4	90	2.6	82	2.4
Rubber	201	5.0	173	5.1	174	5.2
Plastics	125	3.1	21	0.6	12	0.4
Soft Trim, Paper, Cardboard & Components	110	2.7	92	2.7	85	2.5
Sound Deadeners and Sealers	77	1.9	47	1.4	56	1.7
Paint and Protective Dip	26	0.6	20	0.6	17	0.5
Fluids and Lubricants	216	5.4	191	5.6	198	5.9
TOTALS	4014		3415		3355	

TABLE 5

MATERIALS COMPOSITION OF SELECTED AUTOMOBILES

MANUFACTURED RECENTLY IN EUROPE AND JAPAN [13]

	Vehicle Descriptions					
Make	Austin	Ford	Isuzu	Mercedes-Benz	Peugeot	Volvo
Model	1300	Escort 1100 CC	Gemini 1600	6-cyl.	104	144
Approx. curb weight lb.	1898	1717	-	3085	-	2870
	Percentage of Materials by Weight					
Steel & alloys	71.2	-	70.7	59.2	64.0	-
Iron and alloys	10.0	-	14.9	11.1	3.0	-
Total iron & steel	81.2	79.8	85.6	70.3	67.0	71.5
Aluminum	2.4	0.1	1.6	4.2	4.0	1.5
Copper, brass	0.8	0.3	1.3	2.2	0.5	1.5
Zinc	0.5	0.2	-	0.7	-	-
Lead	0.8	-	1.7	1.2	1.5	-
Rubber	4.5	6.8	3.4	5.8	6.0	6.2
Glass	2.7	3.4	3.1	2.3	5.0	3.8
Plastic	2.4	3.9	1.4	-	7.0	4.2
Fibre	1.4	0.6	-	3.4	1.0	-
Hard board	1.3	-	-	1.7	-	-
Paint	0.6	-	-	1.9	1.0	1.2
Miscellaneous	1.4	4.9	1.9	5.9	7.0	10.0

TABLE 6

ESTIMATED PLASTICS USED IN 1974 PASSENGER CARS FROM TWO SOURCES

Material	Usage, lb per Car	
	Garlund [14]	Heinold [15]
Acrylonitrile-butadiene-styrene (ABS)	15	16
Polyester (Glass reinforced)	10	17
Polyamide (Nylon)	6	3.8
Polyethylene	6	5.2
Acetyl, Polyacetyl	2	1.5
Acrylic	3	3.7
Phenolic	5	6
Polypropylene	22	23
Polystyrene	2	-
Poly Vinyl Chloride (PVC)	30	-
Polyurethane	35	-
Styrene-acrylonitrile (SAN)	1	1.2
Other (Cellulostics, Alkyds, epoxies, Polycarbonates, etc.)	12	8.1
TOTALS	149 lb.	85.5 lb.

TABLE 7

BASELINE MATERIALS COMPOSITION: TYPICAL 1975 MODEL AUTOMOBILES SOLD IN THE UNITED STATES

	Automobile "A" Full-Size		Automobile "B" Compact		Automobile "C" Sub Compact		Composite Automobile (sales weighted)[(a)]	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	2400	55.3	1659	55.3	1186	54.4	1896	55.2
Alloy Steel[(b)]	260	6.0	180	6.0	131	6.0	206	6.0
Total Steel	2660	61.3	1839	61.3	1317	60.4	2102	61.2
Cast Iron[(c)]	716	16.5	495	16.5	316	14.5	557	16.2
Aluminum	117	2.7	81	2.7	87	4.0	99	2.9
Copper, Brass	40	0.9	30	1.0	25	1.1	34	1.0
Zinc	35	0.8	24	0.8	17	0.8	28	.8
Lead	25	0.6	22	0.7	20	0.9	23	.7
Other Metal[(d)]	10	0.2	8	0.3	10	0.5	9	.3
Rubber	195	4.5	135	4.5	120	5.5	159	4.6
Glass	100	2.3	75	2.5	60	2.8	83	2.4
Plastic	150	3.5	105	3.5	76	3.5	119	3.5
Other Non-Metal	292	6.7	186	6.2	132	6.0	223	6.5
Totals	4340		3000		2180		3400	

Notes

(a) Assuming 46% Class "A," 32% Class "B," 22% Class "C"

(b) Including stainless steels.

(c) Including malleable iron.

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

The recent automotive trade literature is replete with citings of weight savings that are possible in automobiles. Possibilities for weight savings by size reduction alone are quite evident; e.g., the length and wheel base of the Mercedes Benz 450SE are 195 inches and 113 inches, respectively, which may be compared to the 220 inches and 120 inches of an average full size American car with equivalent interior space. Smaller cars (size categories B and C) have lesser, but still substantial, potential for size reduction. The following examples of weight saving by material substitution have been published recently:

- The Vega aluminum alloy engine block weighs 36 pounds, a savings of 51 pounds over an equivalent iron block. The weight reduction has been attributed to a combination of reduced material density and the greater precision of the die casting process when compared with iron foundry practices.[16]

- A comparative study of the weight of an automobile hood fabricated from different materials gave the following results:[17]

Steel	- 75 lbs.
Aluminum	- 37 lbs.
Fibre glass reinforced plastic	- 34 lbs.

- A zinc die casting for the 1973 Pontiac side window louvre weighing about 20 pounds was replaced by an injection molded, fibre glass reinforced plastic part weighing less than 5 pounds.[17]

- Weights of steel vs. aluminum components have been estimated to be: 90 lbs. vs. 35 lbs. for hoods; 75 lbs. vs. 30 lbs. for trunk lids; 250 lbs. vs. 100 lbs. for four doors; 140 lbs. vs. 60 lbs. for two front fenders; 130 lbs. vs. 50 lbs. for two bumpers.[18]

- The die cast aluminum intake manifold used in some Mustang and Pinto cars saves 15 lbs. compared to a cast iron manifold.[19]

- Volkswagon has introduced a blow-molded, polyethelene gas tank which weighs 8 lbs. compared to 11.3 lbs. for an equivalent steel tank.[20]

- An experimental aluminum body to replicate a given steel design in form and performance was fabricated and showed a 39% saving in weight compared to the steel body.[21]

Industry projections of increased penetration of aluminum and plastics into automobile materials composition appear to be fairly cautious. Table 8 shows some projections by the Aluminum Association.[22] Plastics usage of 200 to 300 lbs. per car has been deemed possible by 1980.[23]

Since cars for the 1980 model year will be manufactured starting at mid-year 1979, and will be in the active design stages in 1976, many basic decisions regarding their design, materials, and tooling will be made within a year from now. Radical changes from current practice are therefore unlikely, at least on an industry-wide scale. We can be fairly certain that the basic body structures of most 1980 model cars will be fabricated by techniques and from materials used on today's assembly lines. The basic structure will be assembled from steel stampings using conventional fastening techniques; e.g., spot welding. Modules added to the basic structure, so-called "hang-on" parts like doors, hoods, trunk lids, and fenders, are more likely to be made of substitute materials.

For the 1990 model year forecasts, we can be more venturesome in projecting changes. All aluminum bodies become a strong possibility, as well as aluminum bodies with plastic hang-on parts.

TABLE 8

ESTIMATED AVERAGE USAGE OF ALUMINUM IN

INTERMEDIATE* CLASS PASSENGER CARS[22]

	Current	Potential	
	1974	1980	1985
Item	lb	lb	lb
Castings	57.25	67.00	206.25
Trim	8.90	9.00	12.90
Air Conditioners	8.10	11.00	12.00
Bumpers	4.25	35.00	50.00
Body Sheet	0.22	58.00	255.00
Miscellaneous	3.58	20.00	39.60
Total	82.30	200.00	575.75

(*) "Intermediates" are included in Category "A" cars.

Our forecasts for 1980 are shown in Tables 9, 10, and 11 for the "maximum credible aluminum," "maximum credible plastic," and "most probable materials" scenarios respectively. Tables 12, 13, and 14 are similarly arranged to exhibit our 1990 projections. The numbers were computed by considering item-by-item substitution possibilities, the corresponding weight savings, and estimating a fraction of production changeover. We also have considered the compounding effect of weight savings. For each pound of weight saving in the upper structure of the car, another half-pound can be saved, in aggregate, in the engine, transmission and drive train, chassis, brakes, wheels, tires, etc.[18, 24]

Other assumptions included in our projections are:

- Reductions in overall car size, especially in the "A" category.
- Smaller engines in response to continued lower speed limits and emphasis on fuel economy.
- An estimate that 80% of cast iron is replaceable by aluminum and that penetration by aluminum into these components will be 60% for the "maximum credible aluminum" scenario and 20% for the other scenarios in 1980, rising to 100% and 40% respectively in 1990.
- For hang-on parts, the penetration percentages are for 1980:

  Maximum aluminum scenario - 50% Aluminum, 10% Plastic
  Maximum plastics scenario - 50% Plastics, 10% Aluminum
  Most probable scenario - 20% Plastic, 20% Aluminum.
  In 1990 these penetrations are assumed to be almost complete with some inroads for aluminum into basic body structures.
- Miscellaneous weight savings by use of lighter glass, partial elimination of spare tires and wheels, etc.

TABLE 9

PROJECTED MATERIALS COMPOSITION: 1980 MODEL AUTOMOBILES

BASIS: MAXIMUM CREDIBLE ALUMINUM CONTENT

	Automobile "A" Full Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%	wt., lb	wt.%
Low Carbon Steel	1792	49.6	1184	47.7	909	47.9	1276	48.6
Alloy Steel (b)	247	6.8	171	6.9	126	6.6	179	6.8
Total Steel	2039	56.4	1355	54.6	1035	54.4	1455	55.4
Cast Iron (c)	307	8.5	224	9.0	153	8.0	225	8.6
Aluminum	419	11.6	312	12.6	244	12.9	322	12.3
Copper, Brass	25	.7	18	.7	16	.8	19	.7
Zinc	17	.5	12	.5	9	.5	12	.4
Lead	25	.7	22	.9	20	1.1	22	.8
Other Metal (d)	20	.6	20	.8	20	1.1	20	.8
Rubber	188	5.2	129	5.2	117	6.2	143	5.4
Glass	95	2.6	71	2.9	57	3.0	74	2.8
Plastic	234	6.5	161	6.5	114	6.0	167	6.4
Other Non-Metal	242	6.7	156	6.3	112	6.0	167	6.4
Totals (e)	3611		2480		1897		2626	

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE 10

PROJECTED MATERIALS COMPOSITION: 1980 MODEL AUTOMOBILES

BASIS: MAXIMUM CREDIBLE PLASTICS CONTENT

	Automobile "A" Full Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	1849	48.9	1228	47.1	944	47.6	1321	48
Alloy Steel (b)	250	6.6	173	6.6	127	6.4	181	6.6
Total Steel	2099	55.5	1401	53.7	1071	54.0	1502	54.6
Cast iron (c)	520	13.8	380	14.6	257	13.0	381	13.9
Aluminum	196	5.2	140	5.4	128	6.5	153	5.6
Copper, Brass	35	.9	26	1.0	22	1.1	27	1.0
Zinc	17	.5	12	0.5	9	0.5	12	0.4
Lead	25	.7	22	0.8	20	1.0	22	0.8
Other Metal (d)	20	.5	20	0.8	20	1.0	20	0.7
Rubber	188	5.0	130	5.0	118	6.0	143	5.2
Glass	95	2.5	71	2.7	57	2.9	74	2.7
Plastic	340	9.0	247	9.5	168	8.5	249	9.1
Other Non-Metal	242	6.4	156	6.0	112	5.7	167	6.1
Totals (e)	3777		2605		1982		2750	

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE 11

PROJECTED MATERIALS COMPOSITION: 1980 MODEL AUTOMOBILES

BASIS: MOST PROBABLE MATERIALS CONTENT

	Automobile "A" Full Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	1977	51.2	1332	49.8	1006	49.7	1418	50.4
Alloy Steel (b)	251	6.5	174	6.5	128	6.3	182	6.5
Total Steel	2228	57.7	1506	56.3	1134	56.0	1600	56.9
Cast Iron (c)	523	13.[illegible]	383	14.3	259	12.8	394	13.6
Aluminum	229	5.9	166	6.2	146	7.2	178	6.3
Copper, Brass	35	0.9	26	1.0	22	1.1	27	1.0
Zinc	17	0.4	12	0.4	9	0.4	12	0.4
Lead	25	0.6	22	0.8	20	1.0	22	0.8
Other Metal (d)	20	0.5	20	0.7	20	1.0	20	0.7
Rubber	189	4.9	131	4.9	118	5.8	144	5.1
Glass	95	2.5	71	2.7	57	2.8	74	2.6
Plastic	261	6.8	182	6.8	128	6.3	188	6.7
Other Non-Metal	242	6.3	156	5.8	112	5.5	167	5.9
Totals (e)	3864		2675		2025		2816	

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE 12

PROJECTED MATERIALS COMPOSITION: 1990 MODEL AUTOMOBILES

BASIS: MAXIMUM CREDIBLE ALUMINUM CONTENT

	Automobile "A" Full Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	1198	38.4	760	35.5	594	36.7	837	37
Alloy Steel (b)	272	8.7	188	8.8	139	8.6	197	8.7
Total Steel	1470	47.1	948	44.3	733	45.3	1034	45.7
Cast iron (c)	135	4.3	87	4.1	43	2.6	87	3.8
Aluminum	720	23.1	530	24.8	398	24.6	543	24.0
Copper, Brass	19	0.6	13	0.6	12	0.7	15	0.7
Zinc	10	0.3	8	0.4	6	0.4	8	0.4
Lead	20	0.6	18	0.8	17	1.1	19	0.8
Other Metal (d)	35	1.1	35	1.6	35	2.2	36	1.6
Rubber	158	5.1	127	5.9	101	6.2	128	5.7
Glass	90	2.9	68	3.2	54	3.3	70	3.1
Plastic	242	7.8	167	7.8	118	7.3	173	7.6
Other Non-Metal	218	7.0	140	6.5	101	6.2	151	6.7
Totals (e)	3117		2141		1618		2264	

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE 13

PROJECTED MATERIALS COMPOSITION: 1990 MODEL AUTOMOBILES

BASIS: MAXIMUM CREDIBLE PLASTICS CONTENT

	Automobile "A" Full Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted)[a]	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	1319	40.5	825	37.3	675	40.0	924	39.3
Alloy Steel [b]	275	8.4	173	7.8	127	7.5	188	8.0
Total Steel	1594	48.9	998	45.1	802	47.5	1112	47.3
Cast Iron [c]	290	8.9	200	9.0	119	7.1	200	8.5
Aluminum	295	9.1	214	9.7	178	10.6	227	9.7
Copper, Brass	19	0.6	13	0.6	12	0.7	14	0.6
Zinc	10	0.3	8	0.4	6	0.4	8	0.3
Lead	20	0.6	18	0.8	17	1.0	18	0.8
Other metal [d]	35	1.1	35	1.6	35	2.1	35	1.5
Rubber	158	4.8	127	5.7	101	6.0	128	5.4
Glass	90	2.8	68	3.1	54	3.2	70	3.0
Plastic	530	16.3	392	17.7	262	15.5	390	16.6
Other Non-Metal	218	6.7	140	6.3	101	6.0	150	6.4
Totals [e]	3260		2213		1687		2352	

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin , magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

TABLE 14

PROJECTED MATERIALS COMPOSITION: 1990 MODEL AUTOMOBILES

BASIS: MOST PROBABLE MATERIALS CONTENT

	Automobile "A" Full Size		Automobile "B" Compact		Automobile "C" Sub-Compact		Composite Automobile (sales weighted) (a)	
	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%	wt.,lb	wt.%
Low Carbon Steel	1649	47.5	1074	45	837	46.3	1168	46.3
Alloy Steel (b)	276	8.0	191	8	141	7.8	200	7.9
Total Steel	1925	55.5	1265	53	978	54.1	1368	54.2
Cast Iron (c)	290	8.4	200	8.4	119	6.6	200	7.9
Aluminum	389	11.2	289	12.1	228	12.6	299	11.9
Copper, Brass	19	0.5	13	.5	12	.7	14	0.6
Zinc	10	0.3	8	.3	6	.3	8	0.3
Lead	20	0.6	18	.8	17	.9	18	0.7
Other Metal (d)	35	1.0	35	1.5	35	1.9	35	1.4
Rubber	158	4.6	127	5.3	101	5.6	128	5.0
Glass	90	2.6	68	2.8	54	3.0	70	2.8
Plastic	316	9.1	228	9.5	156	8.6	231	9.2
Other Non-Metal	218	6.3	140	5.9	101	5.6	151	6.0
Totals (e)	3470		2391		1807		2522	

Notes

(a) Assuming 30% Class "A", 37% Class "B", 33% Class "C" including imports

(b) Including stainless steels

(c) Including malleable iron

(d) Including tin, magnesium. Alloying materials such as manganese, nickel, chromium, and tungsten are included in the steel weights.

(e) Total dry weights without fuel or fluids

Each table showing our projections (and Table 7 for typical 1975 models) shows a "composite automobile" materials composition, which is just a sales weighted average of the materials composition for the A, B and C size cars. (We also have used a domestic production weighted average when considering material demands.) The basis for the sales weighting percentages is shown in Fig. 1 where percent of market share is plotted against year. The data base for 1968 to 1975 (only the first two months of 1975 sales data were available at the time this estimate was made) was received from the Motor Vehicles Manufacturers Association of the U.S., Inc.[25] They use a seven category breakdown which is related to weight but includes some anomolies apparently due to price; e.g., the Corvette (approximate weight of 3400 lbs.) sales are included in a grouping with cars weighing 1400 to 2000 lbs. more. By obtaining manufacturers specified weights for the most common variant of each model, we were able to reaggregate the MVMA data into our "A," "B," and "C" size categories with reasonable confidence. Sales of foreign made cars in the U.S. were not categorized and we apportioned them evenly between our Car B (compact) and Car C (Subcompact) categories.

As can be seen in Figure 1, the data appears to have well developed trends, with the downward trend for Car A being accentuated for 1975, the upward trend for Car B similarly accentuated, while for Car C the data remains fairly close to its recent historical trend. The linear trend extrapolations to historical data obviously cannot continue indefinitely. We have postulated a leveling off of the Car A market share at 30% beginning about 1979 based on the following judgment.

- A minimal market for six passenger (or larger) cars will exist for suburban families.

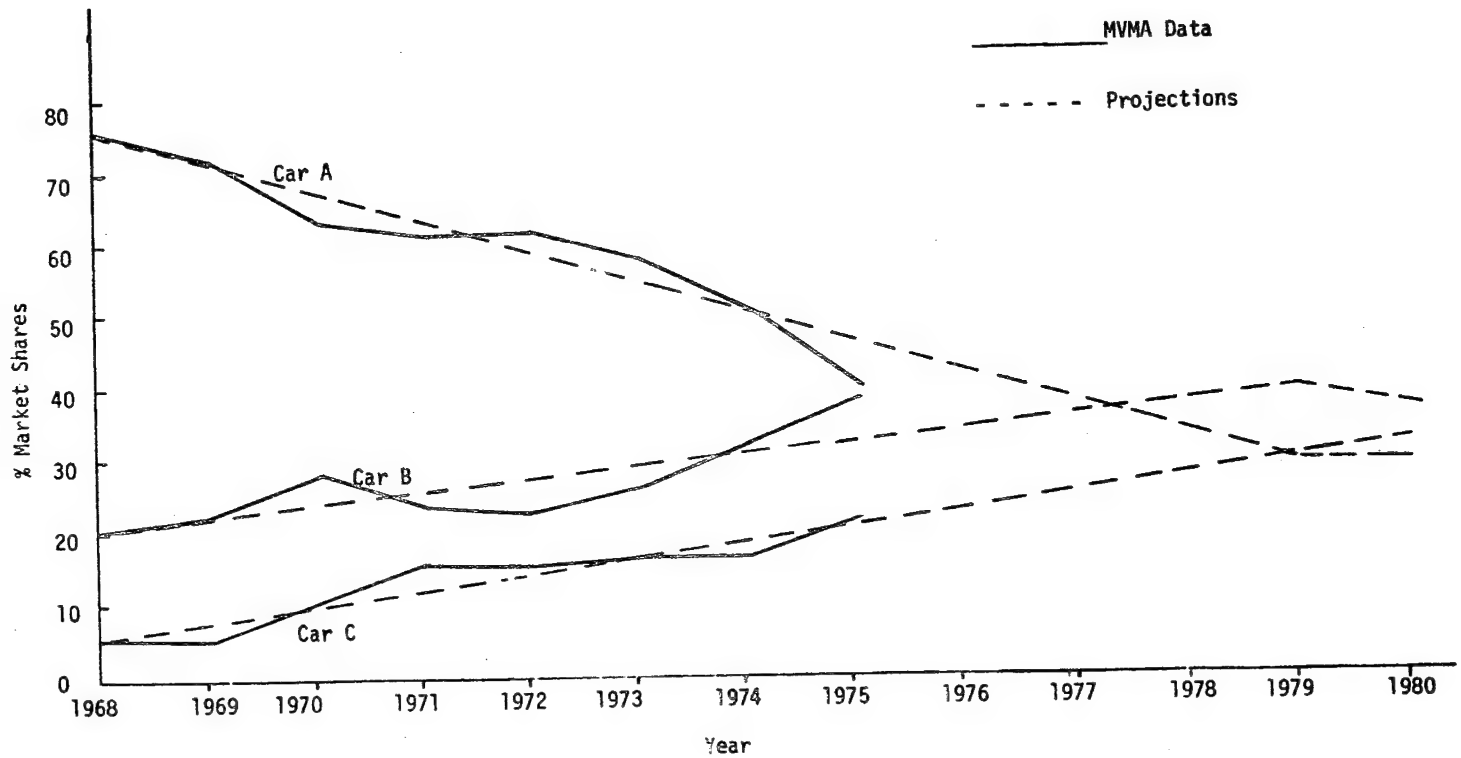

Figure 1. Projected Market Share for Motor Vehicle Size Categories

- The weight of the Car A category will decrease and its fuel economy improve with time, so that the incentive for individuals to substitute a B size car will decrease.

- The status symbol value of largeness and luxury in cars will not entirely disappear. (Even though luxury cars will get smaller; e.g., Chrysler "Cordoba" and Cadillac's "Seville," they probably will never diminish to the Car B size category.)

SECTION III

SAFETY AND PERFORMANCE CONSIDERATIONS

The object of materials substitution is to obtain equivalent part-for-part performance with a decreased weight of material. The possibilities depend then on the mechanical properties of the competing materials, the function of the component, and the operating environment. Table 15 has been assembled to allow comparisons between some of the steels, aluminum alloys, and plastics which are or have been proposed for automotive use. Without belaboring the obvious, the following observations are pertinent:

- Important steel to aluminum ratios for alloys with comparable tensile strenth and elongations are:
  - density ~ 2.8 to 1
  - elastic modulus ~ 3 to 1
- Glass laminate epoxy has the highest strength to weight ratio of any material listed.
- Glass fibre reinforced plastics have low elongation, 5% or less.
- Iron and steels have no competition for high strength, high temperature applications.

Many automobile components function primarily as shields or covers and/or provide cosmetic benefits. Included in this category are "hang-on" parts like hoods, trunk lids, and some fenders. Where these nonstructural parts are formed from mild steels, guage-for-guage substitution of aluminum for steel with a consequent weight saving factor of 2.8 is possible. Approximately double thicknesses of a reinforced plastic; e.g., glass fibre reinforced polyester, could also be substituted for steel, with the weight saving factor for equal tensile strength working out to about two.

TABLE 15

MECHANICAL AND PHYSICAL PROPERTIES OF STEELS, ALUMINUM ALLOYS AND PLASTICS

Material/Alloy Designation/ Composition	Specific Gravity	Yield Strength 10^3 psi e	Tensile Strength 10^3 psi e	Elongation %	Tension Mod. 10^6 psi e	Hardness d Brinell No.	Max. Serv. Temp. °F f	Where Used g
Iron/Grey Cast	6.95-7.35	---	33-45	---	16-20	187-240	1000	Automobile Engine Blocks
Iron/Pearlitic Malleable	7.2-7.45	43-70	60-90	2-10	28	163-285	1000	Crank Shafts, Connecting Rods
Steel/Low Carbon/1008	7.8-7.9	35	50	30-48	~ 30	95	1000	Auto Bodies, Frames
b Steel/HSLA/980x	7.8-7.9	80	95	10	28-30	~200	1000	ESV Frames, Bumper Bars
Steel/9Ni,4Co, 0.2C	7.8	180	190	14	~ 30	360-390	1000	ESV Frames, Roof Supports, Bumper Bars
Steel/Maraging/18% Ni	~ 8	275-300	280-305	6-12	~ 30	550-600	1000	ESV Structure
Steel/Stainless/410 Tempered	7.8	85	110	23	28-32	225	1250	Corrosion Resistance Needed
Steel/Stainless/301 Annealed	7.8	40	110	60	28-32	162	1600	Corrosion Resistance Needed
Aluminum/2036-T4	2.8	27	48	24	10.6	---	400	Reynold's Aluminum Auto Body
Aluminum/6061-T6	2.7	31-40	42-45	12-17	10	95	400	ESV Bumper Bar
Aluminum/7178-T6	2.82	78	88	10-11	10.4	145	300	ESV Bumper Bar
Aluminum/F132	2.74	28	36	1	11.6	105	500	Automobile Engine Pistons
Aluminum/380	2.71	24	48	3	10.3	65-100		General Purpose Casting Alloy
Aluminum/390	2.7-2.8					9		Vega Engine Block
Plastic/ABS/Hi-Temp	1.05	---	6.5-8	3-20	0.3-0.4	Small	190-230	Bright Finish Trim Parts
Plastic/ABS/Glass Filled	1.23-1.36	---	8.5-19	2.5-3	0.6-1	Small	200-230	
Plastic/Epoxy/Plain	1.1-1.4	---	4-13	3-6	0.3	Small	250-550	
Plastic/Epoxy/Glass Fibre Filled	1.6-2.0	---	10-30	4	3	Small	300-500	
a Plastic/Epoxy/Glass Laminate	1.75-2.-	---	110-215	3-4	5.5-8.9	Small	325	High Strength Applications
Plastic/Nylon/Type 6 Cast	1.15-1.17	---	11-14	30-320	.35-.45	Small	180-250	
Plastic/Nylon/Type 6/Glass Filled	1.34-1.42	---	22-25	3	1	Small	200-300	
Plastic/Polyethelene/ Hi-density	0.94-0.97	---	3.1-5.5	20-300	0.06-0.18	Small	250	VW Gas Tank
Plastic/Styrene-butadiene Thermoplastic	0.93-1.1	---	0.6-3	300-1000	<0.05	Small	130-150	Elastomer Required
Plastic/Polyester/Glass Reinforced	1.35-2.30	---	15-30	0.5-5	0.8-2	Small	300-350	Fibre Glass Body Parts, Boats, etc.
Plastic/Polypropylene/ Inert Filled	1.0-1.3	---	4.5-8.2	3-20	1-1.7	Small	290-310	Battery Cases, Ducts, Shrouds

NOTES TO TABLE 15

[a]Nonwoven continuous glass filament base.

[b]HSLA-High-Strength, Low-Alloy

[c]ESV-Experiments safety vehicle-DOT sponsored program with four manufacturers.

[d]Load in Kg. divided by indentation area in mm^2 for 10 mm diameter ball pressed into surface. Test conditions differ for steel and aluminum.

[e]At 70° - 80° F.

[f]For steel and plastic, recommended service temperature from references. For aluminum, approximate temperature for 50% decrease in yield strength.

[g]For engine block service, cylinder walls are etched to expose silicon inclusions. Wear surface thus has hardness of silicon, about the same as iron.

References: 26, 27, 28, 29, 30, 31, 32, 33

For structural components which provide rigidity under load, the three-to-one disparity in elastic modulus between steel and aluminum must be taken into account. The actual increase in guage thickness that would be required in going from steel to aluminum to maintain the same structural rigidity is dependent on the cross-sectional shape of the individual members and the degree of redundancy in the structure. When the Reynold's Aluminum Company designed an aluminum body as a direct substitute for a steel design,[21] they found that it was necessary to increase guage thickness by an average factor of 1.4. This resulted in the aluminum structure having a greater margin below yield strength compared to the steel structure. The realized weight saving was on the order of 40%.

Engine blocks would seemingly be prime candidates for replacement of cast iron by an aluminum casting alloy of comparable strength and good high temperature characteristics, like F-132. In fact, aluminum blocks with cast iron cylinder inserts have appeared from time-to-time on production automobiles, the last flurry occurring in the early 1960's. The need for the cast iron inserts is due to the poor wear properties of aluminum, and ultimately to the relative hardness of the materials. The Brinell hardness numbers in Table 15 are not strictly comparable between aluminum and steel, because the test conditions (i.e., the applied test load) are different. That there is a large difference in hardness is, however, readily apparent.

The aluminum block Vega engine is constructed without cast iron inserts. A hard wear surface on the cylinder walls is obtained by using an alloy which contains a large percentage (16 to 18) of silicon. Chemical etching of the cylinder walls causes a slight recession of aluminum relative to the silicon inclusions, leaving a wear surface that is primarily silicon. Silicon has a hardness comparable to iron.[36] The Vega engine is vulnerable to overheat-damage; e.g., from loss of cooling fluid. If temperatures in the cylinder walls rise much above

500°F, softening of the aluminum and permanent damage to the cylinder walls are likely. With strong incentives for weight reduction now operating, it will be interesting to see which form of aluminum engine block receives greatest acceptance.

Other engine castings can, and often are, made of aluminum; e.g., cylinder heads and intake manifolds, although steel inserts are required for valve seats. Aluminum exhaust manifolds would probably require provisions for cooling. High stress parts, like connecting rods and crank-shafts are not likely candidates for replacement of iron by aluminum, because the possible weight saving is negligible; i.e., three times as much material volume would be required to obtain the same stiffness in these members.

A perusal of current safety standards[34] issued by the National Highway Traffic Safety Administration (NHTSA) of the Department of Transportation reveals only four that could impact on the possibilities for replacing steel by aluminum or plastics. These are:

- No. 214 Side Door Strength
- No. 215 Exterior Protection (bumper impacts)
- No. 216 Roof Crush Resistance
- No. 301 Fuel System Integrity

As presently written it appears that none of these standards would inhibit materials substitution.

Standard No. 215 requires passenger cars to withstand impacts of 5 mph. and 2.5 mph. on front and rear bumpers respectively without damage to lighting, fuel, exhaust, engine cooling or latching systems. Passenger cars which meet these standards have bumper bars made from either steel (most cars), or aluminum (Vega), or fibreglass reinforced plastic (Renault). Since yield strength is the operative criterion in this case, the possible weight saving factor over the usual mild, low carbon steel fabrication is between 2.5 and 5 for aluminum and from 3 to 20 for glass reinforced polyester or epoxy. However, it is also evident

from Table 15 that weight saving factors between 2 and 5 are possible by the use of higher strength steels.

Standards No. 214 and 216 specify crush resistance requirements on doors and roof structures. The forces involved and the specified crush distances do not appear to preclude use of aluminum structural members to replace steel, either wholly or in part. (The aluminum body designed by Reynolds[21] was stated to be equivalent in strength, or better, to its steel counterpart.) Fibreglass reinforced body panels would, however, require aluminum or steel backup structure because of the very limited elongation available. According to a General Motors source,[35] the Corvette fibre glass body uses steel backup structure to meet these standards.

The advent of the plastic fuel tank on Volkswagons and the historical use of aluminum for truck fuel tanks eliminates any doubts about satisfying standard No. 301 with light weight materials. Since the usual steel gasoline tank is virtually certain to rust out at least once in an average car lifetime (on the order of ten years), an alternate construction material is long overdue.

One other safety standard that should be mentioned in passing is No. 302 - Flamability of Interior Materials. It requires that seat covers, padding, headliners, dashboards, and other interior materials be "fire-retardant." Most of these materials are already made of plastics or composites of plastics and fibres, either natural or synthetic. All plastics will burn to some extent, being principally hydrocarbons. However, PVC, polycarbonates, and fluorocarbons tend to be inherently fire retardant because they release gasses during thermal decomposition which tend to smother the flame. Fire retardation in plastics is obtained or enhanced by using fillers such as phosphates, chlorinated synthetic polymeric materials, antimony oxide and other compounds containing bromine, chlorine, antimony and phosphorous.[37] The principal implication for resource recovery is that the plastics used in automobile interiors will

be heterogenous in the extreme, making their reclamation for reuse difficult and probably impossible. Fire retardant fillers also cause the plastics to be less valuable as fuels, first because they must be mixed with substantial quantities of high quality fuels for sustained combustion, and second because the fillers tend to form noxious gasses or residues during burning which may have to be removed from flue gasses. For instance, hydrochloric acid is among the combustion products of PVC and other chlorinated polymers.

Looking further afield, we note that NHTSA has recently completed an Experimental Safety Vehicle[28] program in which four manufacturers were given contracts to design and fabricate "family sedan" prototypes which met very severe safety standards. One aspect of design which the NHTSA program addressed and which is of particular concern to the choice of materials for automobile construction was "crash energy management."* One set of test conditions involved frontal impacts with a pole or barrier at 50 mph. The deceleration experienced in the passenger compartment following the impact was to be limited to 40 "g's," necessitating a deceleration distance of over 25 inches. The two manufacturers who were not primarily in the automobile business (AMF and Fairchild Industries) used long stroke hydraulic cylinders,[29] while the other two (GM and Ford) designed collapsing body structures.[29,30,31]

With either design philosophy, the amount of energy to be absorbed and the resistance force levels that have to be developed in a collision are directly proportional to the total mass that must be decelerated. Hence there is a very great incentive to keep weight in the vehicle body down to the lowest possible value. There is a compounding

*The term "crash energy management" derives from the fact that in a collision with a fixed, rigid barrier, the kinetic energy of the moving body must be dissipated, appearing as thermal energy in deformed structure, or in other places such as the fluid in a hydraulic "shock" absorber.

effect in that the weight of the energy absorbing system will be proportional to the deceleration forces required. It is interesting to note that in spite of these incentives, all of the prototype cars built for the NHTSA program were very heavy vehicles, considerably heavier, in fact, than the project specification, which called for a 4000 lb. vehicle. Weights ranged from about 6000 lbs. for the AMF vehicle to about 5000 lbs. for the GM vehicle.[29]

Table 16 lists the materials actually used by the four ESV manufacturers in their prototype cars. As such, it gives a preliminary view of materials which might come into use if severe crashworthiness standards were ever promulgated. Some materials choices shown; e.g., those for engine blocks and radiators, might reflect program funding limits rather than designer choices; i.e., readily available components may have been used.

The most interesting comparisons occur in the choices for highly stressed components. For instance, choice of material was unanimous in the frame and roof support structures all manufacturers designed using a high strength alloy steel. As pointed out in the discussion of material properties, there is no theoretical reason why an aluminum frame of equal strength and approximately equal weight could not be used. However, the overall bulk of the structural members, the increased cross sectional sizes, and greater difficulty in fabricating the large size pieces, probably mitigated against the choice of aluminum as opposed to the high strength alloy steels.

During pole impacts, the bumper face bar is one of the most highly stressed members; it must withstand the full deceleration forces at the center of its own mass and half of the vehicle (less bumper) deceleration forces at each of two attachment points near the ends. The total load on the center of the bumper was calculated to be on the order of 400,000 lbs. by Fairchild.[29] The materials choices and weights for the front bumper bar show that two manufacturers chose aluminum alloys

TABLE 16

MATERIAL CHOICES FOR ESV PROTOTYPES

Manufacturer (Vehicle Curb Weight, lbs.)	Front Bumper Bars	Rear Bumper Bars	Frame	Roof Support Pillars	Doors	Front Fenders	Hood And Trunk Lid	Roof	Floor Panels	Gas Tank	Radiator	Engine Block
Fairchild Industries (5380)	HSA Steel	HSA Steel	HSA Steel	HSA Steel	Aluminum & Steel	NS	NS	NS	Aluminum	Fabric/ Rubber	Copper	Cast Iron
AMF (6005)	Aluminum	Aluminum	HSA Steel*	HSA Steel*	Aluminum & Fiberglass	Fiberglass	Fiberglass	Fiberglass	NS	Nylon Reinforced Elastomeric/ Polyurethane Foam	Aluminum	Cast Iron
GM (5083)	Aluminum	Aluminum	HSA Steel	HSA Steel	Aluminum	Aluminum	Aluminum	Aluminum	Steel	Steel**	Copper	Aluminum
Ford (5565)	HSA Steel	Aluminum	HSA Steel	HSA Steel	Steel	Steel	Steel	Steel	Steel	Nylon Fabric/ Nitrile Rubber/ Polyurethane Foam	Aluminum	Cast Iron

Notes: HSA = high strength alloy
NS = not specified in available references
* = AMF frame encloses passenger compartment--others of more conventional design
** = only fuel tank to fail during crash tests
Reference nos 29, 30, 31

and two chose high strength alloy steels. The weights of the bumper bars were all very close.* We conclude that the weight saving available from the use of aluminum in very highly stressed structural parts is small and high strength alloy steels may be the material of choice in these applications.

Joining aluminum by spot welding, arc welding or with compatible connectors presents manufacturing problems not present with steel. The lower resistance of aluminum and its propensity to form a protective oxide coating (an advantage in resisting corrosion) makes spot welding more difficult than for steel and requires more expensive equipment and more elaborate techniques. Adhesives in the joint are generally required to bring the strength and fatigue resistance of aluminum spot welds up to the level of spot welds in steel, on a weld-for-weld comparison.[21]

An often heard assertion (at least often heard by the authors in the course of this study) is that use of aluminum will increase automobile life by decreasing corrosion, particularly of body parts. Tests of panels in salt spray show that aluminum fares much better than steel. In one test cited by Hsu and Thompson,[32] a panel of 2036 aluminum alloy was jointed to a panel of 1010 steel and the combination subjected to immersion in sea water and acetic acid for one week. By use of sealants and protective coatings, the aluminum had been preserved from corrosion at the interface while the steel had corroded. However the effectiveness of protective coatings when the joint is continually flexed and strained over a period of years is not established by such a short immersion test.

Since the aluminum has a much higher oxidation potential[36] than iron, the result of having aluminum and iron or steel in direct contact with each other and with an electrolyte, such as a salt solution, will be galvanic corrosion of the aluminum. The iron will corrode less than if the aluminum were absent. Insulating the iron from the aluminum, using a paint or other nonconducting coating in the steel-aluminum joint, will stop the galvanic action and the iron will corrode at whatever rate it would in the absence of the aluminum. A conducting path through

*Bumper bar weights were: GM 108 lbs, Ford 90 lbs, AMF 100 lbs, FI 115 lbs.

bolts or other fasteners will negate the effect of the protective coating. If the steel-aluminum joint is subjected to flexures during normal use, it is possible that metal-to-metal contacts will result from rubbing action either at the interface or at the fasteners. Establishment of an electrical conducting path through the interface will allow localized galvanic corrosion of the aluminum to begin.

Alloying elements can effect galvanic corrosion. Thus stainless steels are known to promote galvanic corrosion of ordinary mild steel. Of the two principal alloying metals in stainless steel, chromium has a higher oxidation potential than iron, while nickel has a lower oxidation potential than iron. If aluminum (or magnesium, which has an even higher oxidation potential than aluminum) is interposed in the steel-stainless steel circuit, the aluminum which has a higher oxidation potential than chromium, iron or nickel will be corroded while both steels are preserved until the aluminum is gone. Aluminum has sometimes been used as a "sacrificial" metal in this way.

The assertion that increased use of aluminum will tend to increase automobile longevity thus needs to be carefully examined and qualified. If, for instance, aluminum fenders are used in a "hang-on" mode of construction, while the basic body is made of steel, the expected longevity of the fender will depend, in part, on the effectiveness of the protective coatings and sealants used between the steel body and the aluminum fender, as well as the bushings and washers used to isolate the connectors from direct metallic contact. If the entire body is aluminum, then the potential galvanic corrosion problem occurs at the attachment point to the steel frame. For a unitized body and frame of all aluminum construction, the number of exposed dissimilar metal joints should be small and potential corrosion problem less than for either of the aforementioned types of construction.

The longevity of cars with increased aluminum composition will thus depend strongly on their type of construction and the care taken in their design and manufacture. Sealing and protecting bi-metallic joints in a way that will not deteriorate with use is likely to be expensive and require tight quality controls. Poor design or sloppy manufacturing practices could lead to a decreased life expectancy for automobiles with increased aluminum content.

Plastics do not, of course, have any corrosion problems and may, for this reason, be favored for nonstructural hang-on parts. There is, in fact, a certain appeal to the idea of a fender made of an elastomer that will recover its shape after a minor bumping. Not all fenders are nonstructural, however, and reinforced plastics, such as fibreglass reinforced polyester, will not have this bounce-back property. In fact, repairs to fibreglass body parts are generally more expensive than similar repairs to sheet metal.

The most important limitation to the use of plastics will be the temperature of the operating environment. Engine compartment hoods are a case in point, where temperatures can reach 300° F under severe conditions. This is near the upper limit for most plastics (see Table 15) and prolonged use at such a temperature is likely to cause some deterioration in the plastic; e.g., warping or cracking due to breaking of some of the internal cross linkages of the polymer chains.

SECTION IV

DEMAND, AVAILABILITY AND PRICE OF STEEL AND SUBSTITUTE MATERIALS FOR AUTOMOBILE MANUFACTURE

The consumption needs of the automobile industry (for passenger car production only) relative to present and projected domestic consumption of steel, aluminum and plastics is shown in Table 17. The ranges of values shown encompass the three materials composition scenarios previously defined. The overall assessment from these numbers is that the most important impact will be felt in the aluminum industry where automotive consumption could grow from less than 8% of domestic production in 1973 to as much as 21% in 1980 and 26% in 1985 in the maximum aluminum car scenario. The projected growth of plastics consumption in the total economy is large enough that automotive consumption of plastics never rises above 9% of projected domestic production.

The principal raw materials for the plastics industry are ethane and propane separated from natural gas, and naphtha type hydrocarbons distilled from crude oil. Declining domestic production of natural gas and crude oil might limit the attainable production of plastics if foreign sources become unreliable or prohibitively expensive. However, it should be noted that only 16.6% of available ethane and 45% of available propane[38] were extracted from natural gas in 1973 because economic incentives for deeper extraction were insufficient.* Also more than 50% of propane** was sold for purposes other than petrochemical feedstocks.[39] Therefore, it appears that domestic materials for a greatly expanded plastics industry are available if prices are high enough.

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* Extraction of ethane and propane from natural gas is accomplished by refrigeration. The amount extracted is a direct function of processing costs.

** Principally space heating in rural areas.

TABLE 17

PROJECTIONS OF MATERIALS CONSUMPTION BY AUTOMOBILE MANUFACTURERS AND TOTAL DOMESTIC PRODUCTION

(Millions of Metric Tons)

Material	Automotive Consumption*			Total Domestic Production		
	1973	1980	1990	1973	1980+	1985+
Iron and Steel	16.4	9.8-11.5	8.0-11.1	116.5	112.0-124.5	122.5-126.1
Aluminum	.5	.9- 1.8	1.5- 3.7	6.6 (1.3)**	7.7- 8.5	9.1- 10.4
Plastics	.6	.9- 1.2	1.0- 2.3	13.2	14.0- 15.5	18.2- 19.5

*Assumes production of 10 x 10^6 units in 1980 and 12 x 10^6 units in 1990.
**From domestically produced ore and secondary recovery.
+From SEAS model.

Sources: American Iron and Steel Institute, Motor Vehicle Manufacturers Association, U.S. Bureau of Mines, Modern Plastics, January 1975.

The present dependence of U.S. aluminum production on foreign ore is relatively great. Less than 20% of domestic aluminum production in 1973 was based on domestic raw materials, and recent formation of an international cartel to control bauxite prices has had a large impact on primary aluminum prices. By Bureau of Mines estimates, present prices of aluminum are sufficiently high that extraction from low grade U.S. domestic ores is economically feasible. However, the economic lags are such that it could take as long as 10 years to attain a level of production capacity from domestic raw materials that would equal present domestic consumption.[40] Consequently, the supply of aluminum will remain vulnerable to foreign cartel action, and there is a remote chance that this will inhibit substitution of aluminum for steel in automobiles. In the long run, reserves of aluminum ore are virtually inexhaustible. Expansion of secondary recovery from obsolete scrap* is another expandable source of supply. In 1973 only 3.5% of total aluminum consumption and 19% of secondary recovery came from reprocessing old aluminum scrap.[41]

The competition between aluminum and plastics for shares of the automobile materials market could, in part, depend on material price. We have investigated the possible changes in relative prices of steel, aluminum, and plastics materials (and hence the relative price of the materials entering into the automobile under the three defined materials substitution scenarios) for changing energy price conditions. That material costs are, in the long run, strongly influenced by energy costs is illustrated by the comparative price-time series shown in Table 18.

*"Obsolete" or "old" scrap is obtained from objects that have seen functional use, as opposed to "new" scrap which is obtained from manufacturing waste (cutting, scraps, rejects, etc.).

TABLE 18
COMPARISON OF PRICES BASED ON
WHOLESALE PRICE INDEX (1967=100)

	Crude Petroleum	Electric Power	Aluminum Ingot, Primary	Steel Mill Products	Plastic Materials and Resins
1967	100.0	100.0	100.0	100.0	100.0
1968	100.8	100.9	102.5	102.5	91.9
1969	105.2	101.8	108.9	107.4	90.4
1970	106.1	105.9	113.2	114.2	90.6
1971	113.2	113.6	116.2	123.0	88.9
1972	113.8	121.5	97.0	130.4	88.7
1973	126.0	129.3	101.5	134.1	92.1
1974	211.8	163.1	151.3	170.0	143.8
1974					
Jan	178.4	137.5	119.2	138.1	93.7
Feb	201.7	142.2	119.2	139.0	96.3
Mar	201.7	148.9	139.8	146.6	116.0
Apr	201.7	153.4	148.1	150.0	123.9
May	201.7	159.7	149.6	162.4	128.0
Jun	201.7	164.7	153.6	169.8	140.8
Jul	224.4	167.6	156.8	181.4	147.5
Aug	225.2	170.6	165.8	187.9	160.7
Sep	225.4	173.8	170.5	190.1	174.6
Oct	226.2	178.3	164.6	190.9	179.1
Nov	231.0	179.7	163.9	191.2	181.3
Dec	223.0	180.3	163.9	191.9	183.2
1975					
Jan'	223.1	183.3	159.9	195.9	183.0
Feb	228.6	186.5	158.9	195.6	182.2
Mar	230.2	191.1	158.9	195.6	182.1
Apr	232.2	194.6	157.0	196.3	182.1
May	234.2	192.9			
Jun	256.0	190.6			

Source: Wholesale Price Index, published by Bureau of Labor Statistics.

TABLE 19
COST OF MANUFACTURE AS PERCENTAGE OF TOTAL COST[42,43]

	NonEnergy Raw Materials	Energy Inputs*	Value Added
Ferrous Metals	47.9	9.6	42.5
Aluminum			
--Primary	49.6	9.8	43.6
--Secondary	77.0	4.1	19.9
Plastics			
--HDPE	2.20	26.39	71.41
--LDPE	2.20	26.39	71.41
--Polypropylene	2.15	10.98	86.87
--PVC	17.26	15.57	67.15
--Polyurethane	15.86	.28	83.86
--ABS & SAN Resins	24.69	6.77	68.54

*Includes energy content of petrochemical feedstocks.

TABLE 20

RELATIVE MATERIALS PRICES FOR AUTOMOBILES

	Fixed Energy Prices	Energy Prices Double	Energy Prices Triple	Energy Prices Quadruple
1975 Car	1			
1980 Cars				
Most Probable Materials Composition		0.999	1.069	
Maximum Aluminum Materials Composition		1.002	1.081	
Maximum Plastic Materials Composition		.975	1.055	
1990 Cars				
Most Probable Materials Composition			1.066	1.142
Maximum Aluminum Materials Composition			1.094	1.170
Maximum Plastics Materials Composition			1.025	1.100

Components of production cost for steel, aluminum and certain plastics are given in Table 19. Using these components as weighting coefficients, and 1973 prices as base values, the relative prices of the materials entering automobile manufacture have been calculated for varying assumptions about energy costs. These are shown in Table 20. (A mix of plastics was used, based on the substitution studies of Section II. The proportions of primary to secondary aluminum were adjusted on the assumption that two thirds of new aluminum would be wrought products fabricated from primary production.) The result of this exercise shows a slight advantage to the maximum plastics composition scenario in items of relative materials cost. The differences are not, however, thought to be significant enough to greatly influence materials substitution choices by the automobile manufactures.

SECTION V

IMPACT ON FERROUS METAL RECYCLING INDUSTRIES

The primary product of the automobile recycling industry, at present and for the foreseeable future, is ferrous scrap. At least 50% of the average car will be iron or steel until 1990 under any of the scenarios we have generated. Nonferrous scrap, and in particular aluminum scrap, is a by-product, albeit one that will become more important in the future. Figure 2 shows the essentials of the flow of retired automobiles back into the stream of useful materials.

In Figure 2 we show two heavily bordered blocks which represent delays in moving cars through the recovery system. Autos that are retired at a sufficiently early age (generally less than 6 to 7 years old) have value as a source of reusable parts. (Unless, of course, they are retired by total demolishment.) These newer cars move into auto wrecker/dismantler establishments where they remain for shorter or longer periods depending on the amount of "junk yard" storage space available to the dismantler.

Urban establishments tend to dismantle rapidly, store the parts and keep the stripped hulks for only short periods of time. Because this is a speculative and labor intensive mode of operation, they have to be very selective about the age and condition of hulks they accept for dismantling. Rural auto wreckers tend to do little or no dismantling until the moment a customer arrives desiring a specific part. Thus hulks are kept for a relatively long time and hulks with almost any prospective parts value are accepted.

Retired autos which are not acceptable to the local dismantling industry become a part of what is called "environmental storage." They must be collected, prepared and shipped to an auto hulk processor; for purposes of this study, a shredder. The collector must remove tires, batteries and gas tanks* from the hulks before delivering them to the shredder. He may remove the radiator, wheels, engine, transmission, and

*What happens to gas tanks is a mystery. No entities contacted by the authors admitted to having anything to do with them.

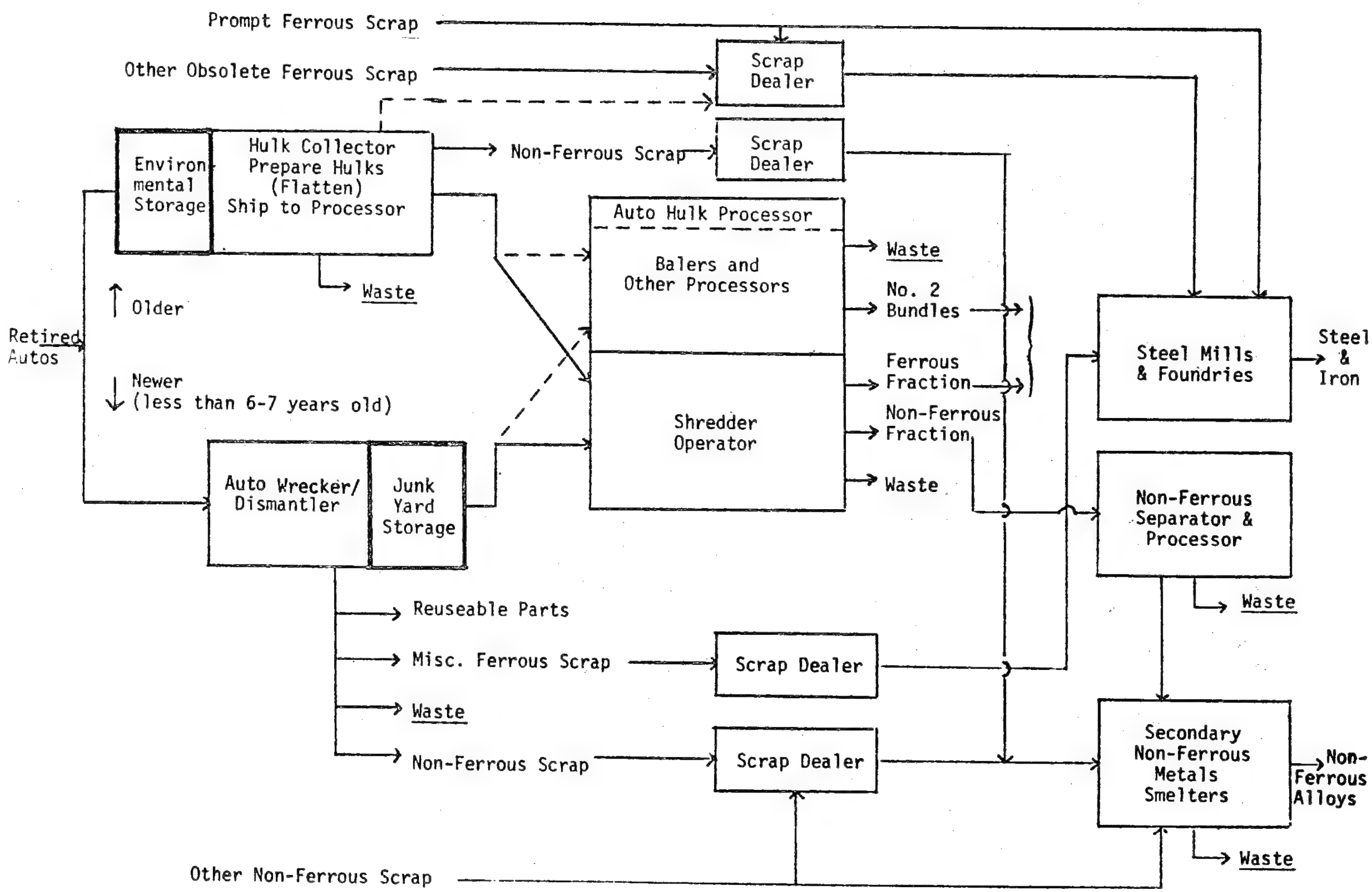

Figure 2. Return Flow of Automobile Materials

differential for disposal through other scrap material market channels if available prices warrant the cost of removal. On the optional items, the choice to remove or not is purely economic. Recent trends appear to be toward less removal of optional items, especially engines and power train components. Apparently shredder operators have no qualms about putting engine blocks and similar ferrous castings through their machines.

The central part of the automobile materials recycling industry is, of course, the auto hulk processor. Until recently, the output of balers exceeded that of shredders but this relationship apparently was reversed in the first quarter of 1975.* We expect the shredders to widen their dominance over balers in the coming years. The advent of autos with substantial portions of their hulks made of nonferrous metals can only tend to accentuate this trend.

Turning first to the ferrous scrap industry, we show in Figure 3 the relationship of scrap from automobile sources to all ferrous scrap in 1973. It should be noted that the total available obsolete scrap in any given year from nonautomotive sources is much greater than the amount of automobile scrap from retired autos. Put another way, the recycling ratio for autos (60% to 80% in 1971) is high relative to many other sources of obsolete ferrous scrap, such as household appliances (30%) and obsolete industrial machinery (5%).

Total domestic scrap requirements have recently been forecast for EPA as shown in Table 21. We note that scrap requirements of the major part of the steel industry; i.e., the basic oxygen and open hearth capacity, are expected to remain essentially constant, despite an increase in production of 22% from 1970 to 1985. The major increase in scrap requirements is expected to be generated by the threefold increase in electric furnace capacity over the same period.

Exports are also a major market for obsolete scrap generated in the U.S. In recent years, U.S. exports of ferrous scrap have been generally in the range of 1.5 to 2% of world steel production except when

*Domestic consumption of shredded scrap totaled 745,057 tons in the first quarter of 1975 vs. 664,287 tons for no. 2 and all other bundles in the first quarter of 1974. Export totals were 567,632 tons vs. 344,438 tons.

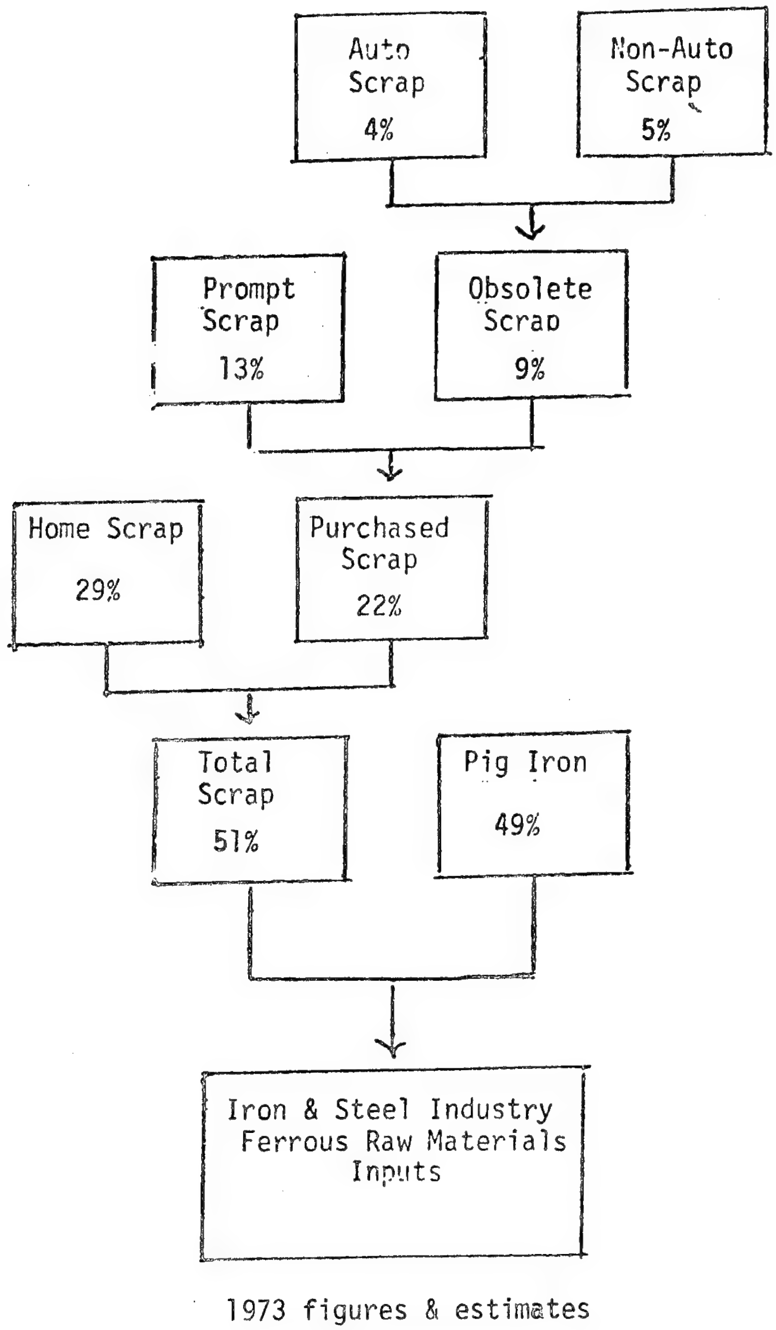

Figure 3. Sources of Ferrous Inputs to Domestic Iron & Steel Industry

TABLE 21

FUTURE DOMESTIC SCRAP REQUIREMENTS*
(million net tons)

Steel Industry	1968-70 Average Prod	1968-70 Average Scrap Req.	1975 Prod	1975 Scrap Req.	1980 Prod	1980 Scrap Req.	1985 Prod	1985 Scrap Req
Basic Oxygen	57.4	19.0	82.0	27.1	105.0	34.7	127.0	41.9
Open Hearth	58.2	27.8	40.0	20.0	25.0	12.5	14.0	7.0
Elecric	19.0	18.2	33.0	32.5	45.0	44.1	59.0	57.8
	134.6	65.0	155.0	79.4	175.0	91.3	200.0	106.7
Blast & Misc.	92.2	7.0	101.0	7.6	112	8.5	124	9.6
		72.0		87.0		99.5		116.3
Iron & Steel Casting Industry	Shipments		Shipments		Shipments		Shipments	
Foundry Furnaces	17.8	17.2	20.0	18.6	23.0	21.4	27.0	25.1
Total Scrap Req.		89.2		105.6		121.2		141.4
Purchased Scrap Req.		34.9		43.9		51.3		61.4
Purchased of Total		39.1%		41.6%		42.3%		43.4%

*Extracted from Regan, James McLeer, et al. Reference no. 2, p. 173.

limited by the Federal Government. In 1973, over 11 million tons of ferrous were exported, of which about 2 million tons were shredded and 1.2 million tons were baled scrap, mostly of automotive origin.

Based on our study of domestic and worldwide steel production, and historic scrap utilization ratios, we project total ferrous scrap requirements as shown in Figure 4. The recent history of shredded and baled scrap utilization,[41] as a percentage of net total domestic receipts of all scrap is shown in Figure 5, along with linear projections to 1985. Although year-to-year data is somewhat ragged, the trend of displacement of baled scrap by shredded scrap is unmistakable. Similar data for exported ferrous scrap is shown in Figure 6. The long term tendency toward displacement of baled scrap by shredded scrap is again apparent but somewhat overshadowed by the steeply rising growth trend of exported shredded scrap. Putting these results together, we arrive at the projections for shredded and baled scrap requirements shown in Figure 7.

Using a methodology similar to that employed by Booz-Allen in an earlier study for EPA,[4] we have developed estimates of automobiles required for processing by shredders and balers, assuming historical input ratios of automobiles to other sources, as nearly as these could be determined. The results are shown in Figure 8. The excess of automobiles retired over those processed in the years prior to 1973 led to a backlog of unprocessed automobiles stored in the environment and in junk yards. This number reached alarming proportions by 1973 - probably on the order of 13.5×10^6 automobiles although the range of uncertainty is large. The projected shortfall of available deregistered automobiles shown in Figure 7 should rapidly deplete this inventory, provided, of course, that alternate sources of scrap do not displace automobile hulks. The projected buildup and depletion of the unprocessed automobile hulk inventory is depicted in Figure 9.

The depletion of the unprocessed automobile inventory will not occur if this inventory is located out of the economic transportation range of a processor. In the course of this study, we have compiled an up-to-date list of shredder operators in the U.S. (see Appendix H) and checked it

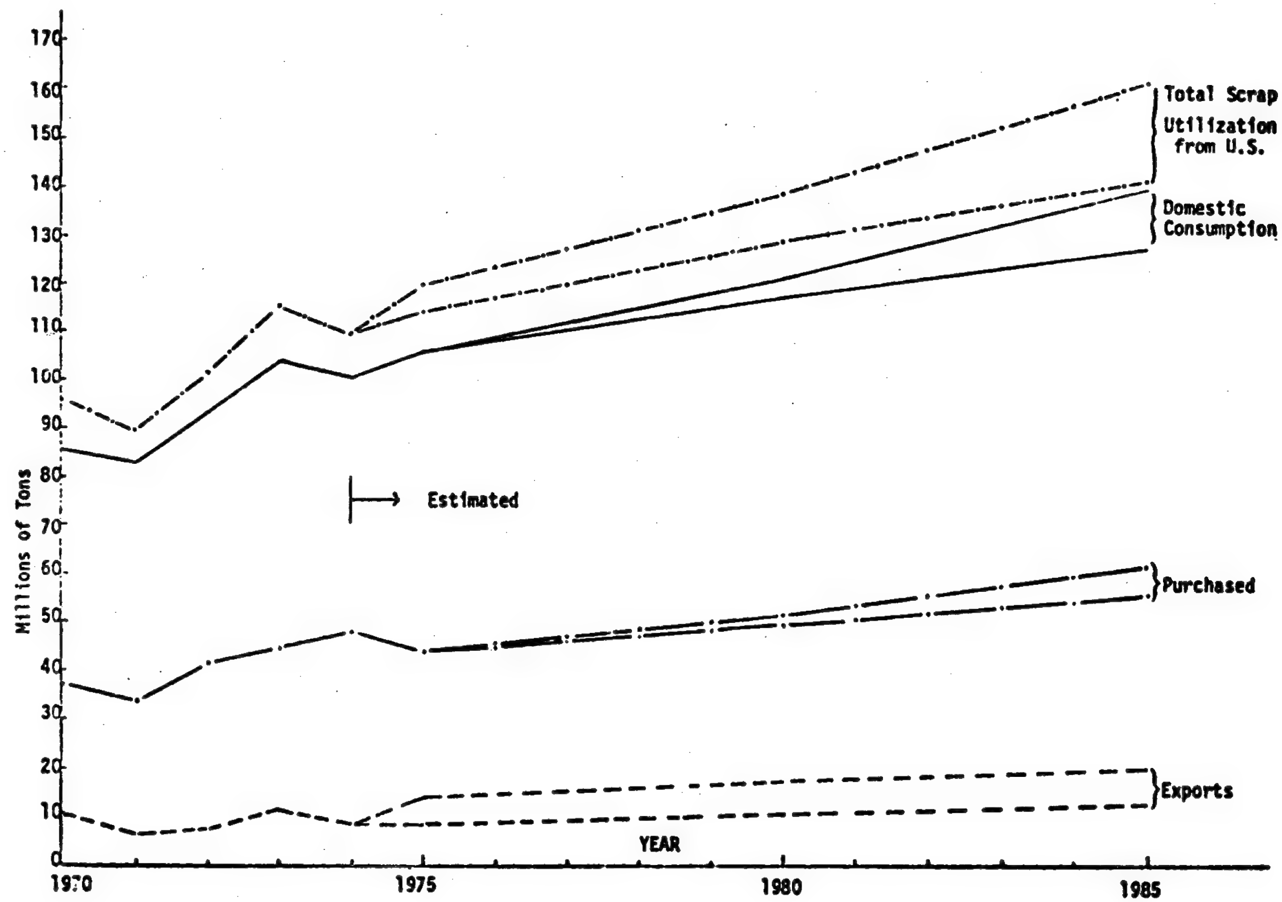

Figure 4. Total Scrap Requirements for the United States

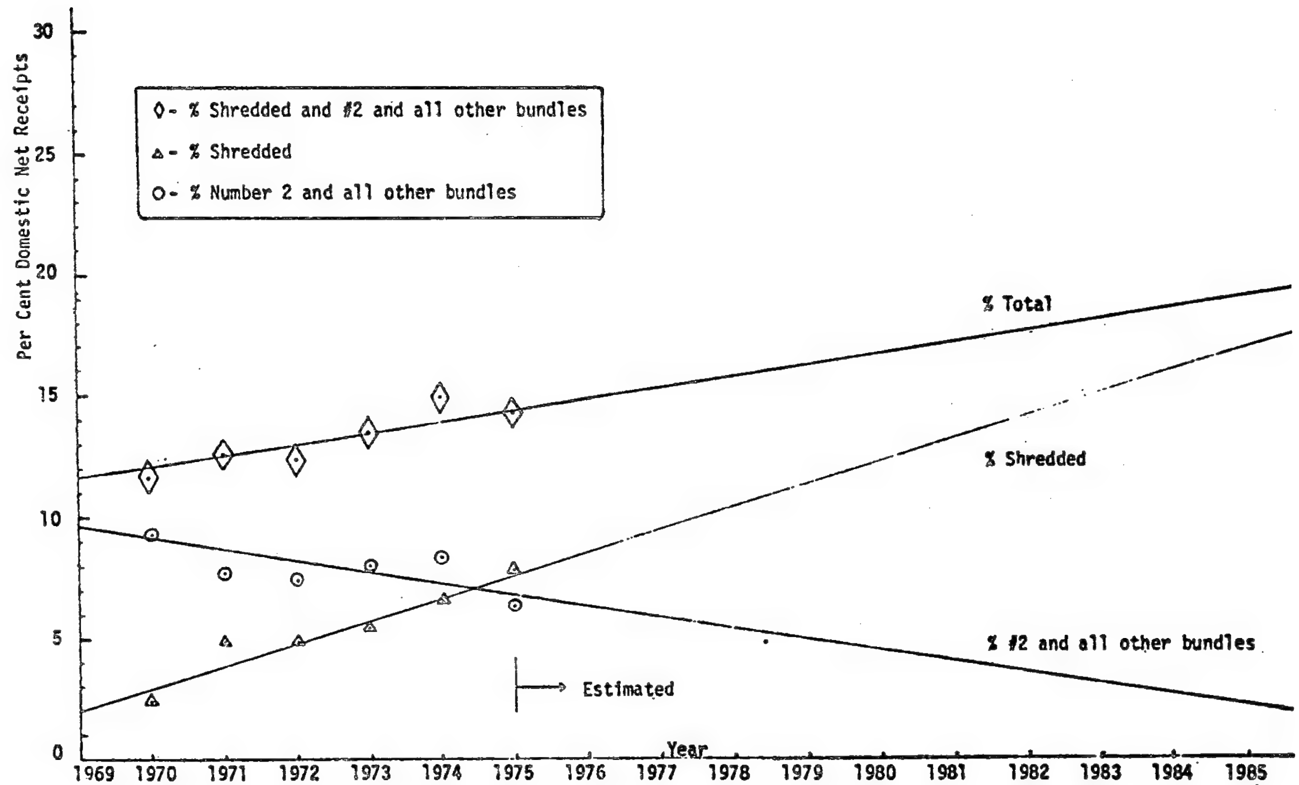

Figure 5. Percentages of Number 2 and All Other Bundles and Shredded Scrap of Net Total Domestic Receipts of Iron and Steel Scrap

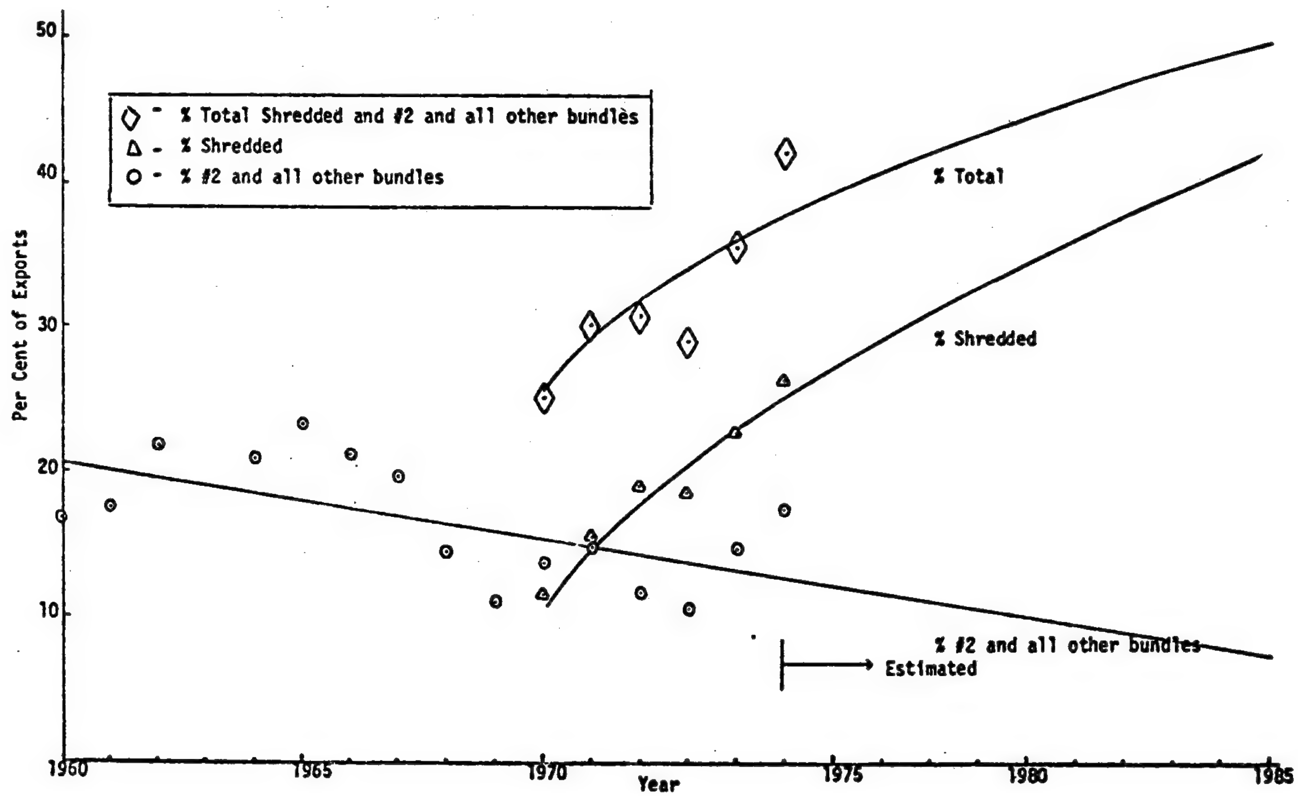

Figure 6. Percentages of Number 2 and All Other Bundles and Shredded Scrap of Exports of U.S. Iron and Steel Scrap

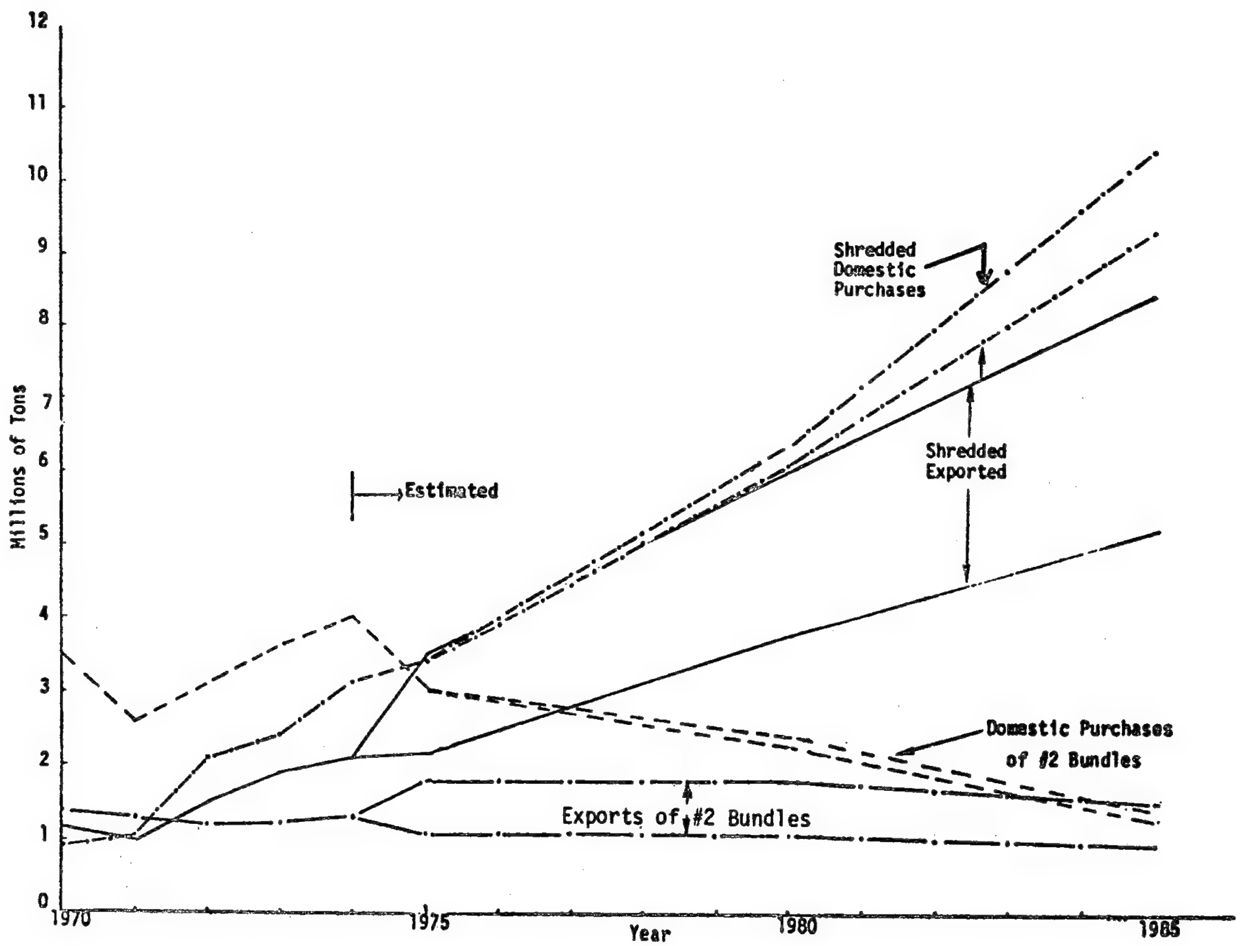

Figure 7. Requirements for Shredded and #2 and All Other Bundled Scrap

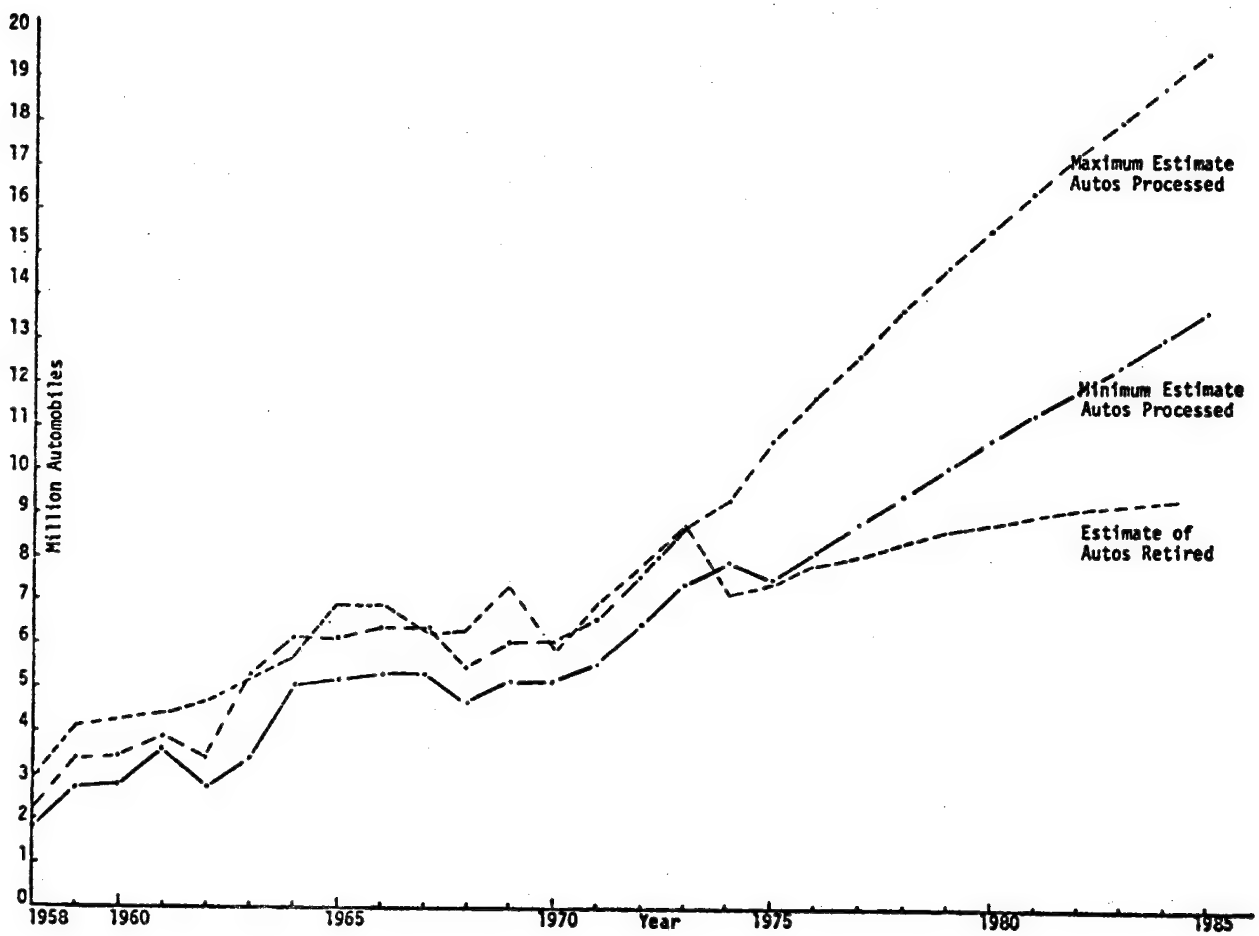

Figure 8. Estimates of Automobiles Retired and Automobiles Required for Processing by Shredders and Balers

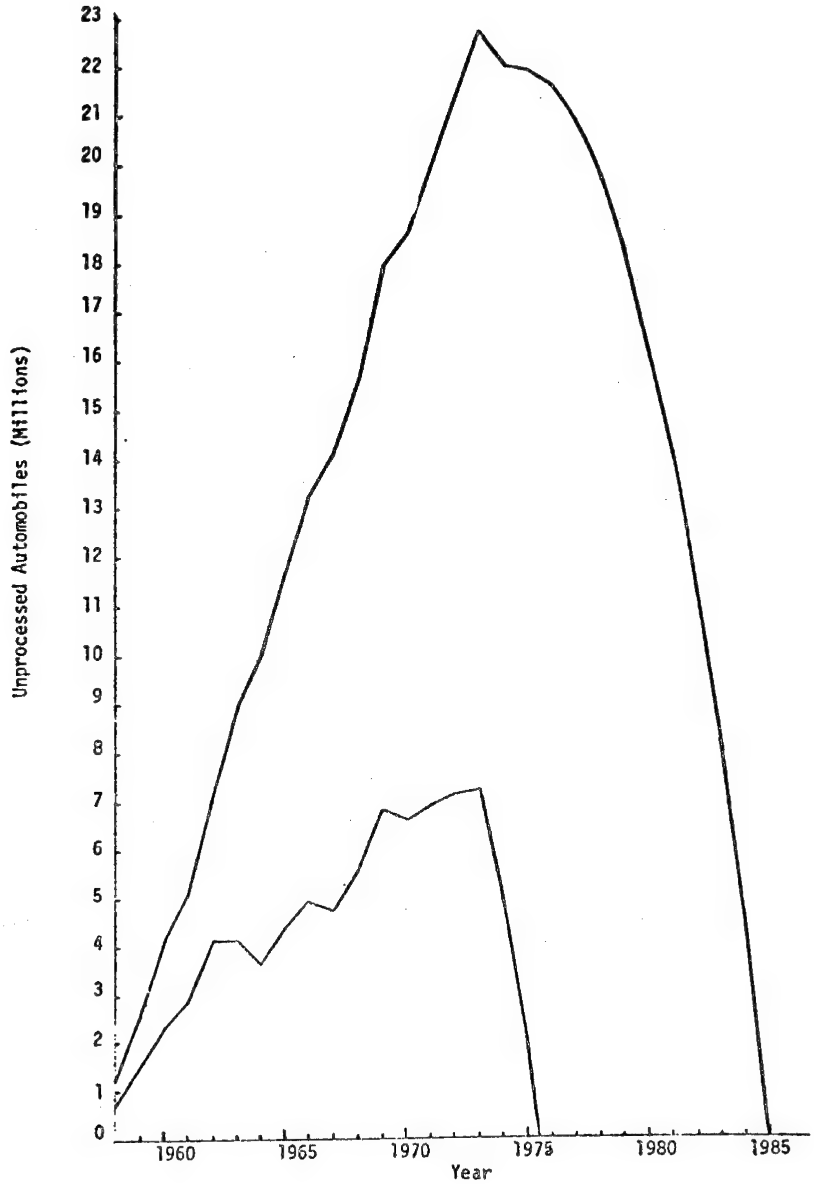

Figure 9. Cumulative Unprocessed Automobiles

against a previous list issued by the Institute of Scrap Iron and Steel in March of 1971. (The 1971 list appears in Adams.[5]) The locations of shredders are shown on the map in Figure 10 together with an indication of the possible areas of the contiguous U.S. where transportation of hulks to the nearest shredder <u>might</u> be unprofitable (shaded).* In his study of the economics of the automobile hulk processing business, Adams** calculated that with shredded scrap prices at $30/ton, a shredder operator with an annual capacity of 50,000 tons or greater could afford to pay for transportation of flattened hulks, 20 to a truckload, for over 400 miles. Present scrap prices for No. 1 heavy melting scrap (shredded scrap equivalent) are in excess of $80 per ton (as of this writing). Deflating this to 1973 price levels gives an equivalent price of $60 per ton. Hence, the economic drawing radius of an average size shredder is well in excess of 400 miles and we can conclude that essentially all of the contiguous U.S. can supply hulks to the presently structured shredder industry.

While presenting the results of this study at the "Technology of Automobile Crushing and Shredding Institute" at the University of Wisconsin-Extension, October 16-17, 1975, the authors had an opportunity to discuss the availability of automobile hulks with shredder operators and hulk collectors from several areas of the country. Their remarks generally confirmed that hulks are becoming harder to obtain, that all the readily accessible hulks in "environmental storage" have generally been salvaged, and that collectors commonly pay for hulks for which in former years they could demand a removal payment. One collector in the Appalachian region of Virginia indicated that he now found it profitable to collect hulks that were abandoned in remote backwoods areas. Recovery of hulks from remote mountainous areas of Appalachia, (e.g., West Virginia, which has no shredders within its borders) may still lag the trend elsewhere but actual salvage statistics could not be obtained from any official source.

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*Alaska and Hawaii have no shredders.
**Ref. #5, page 117.

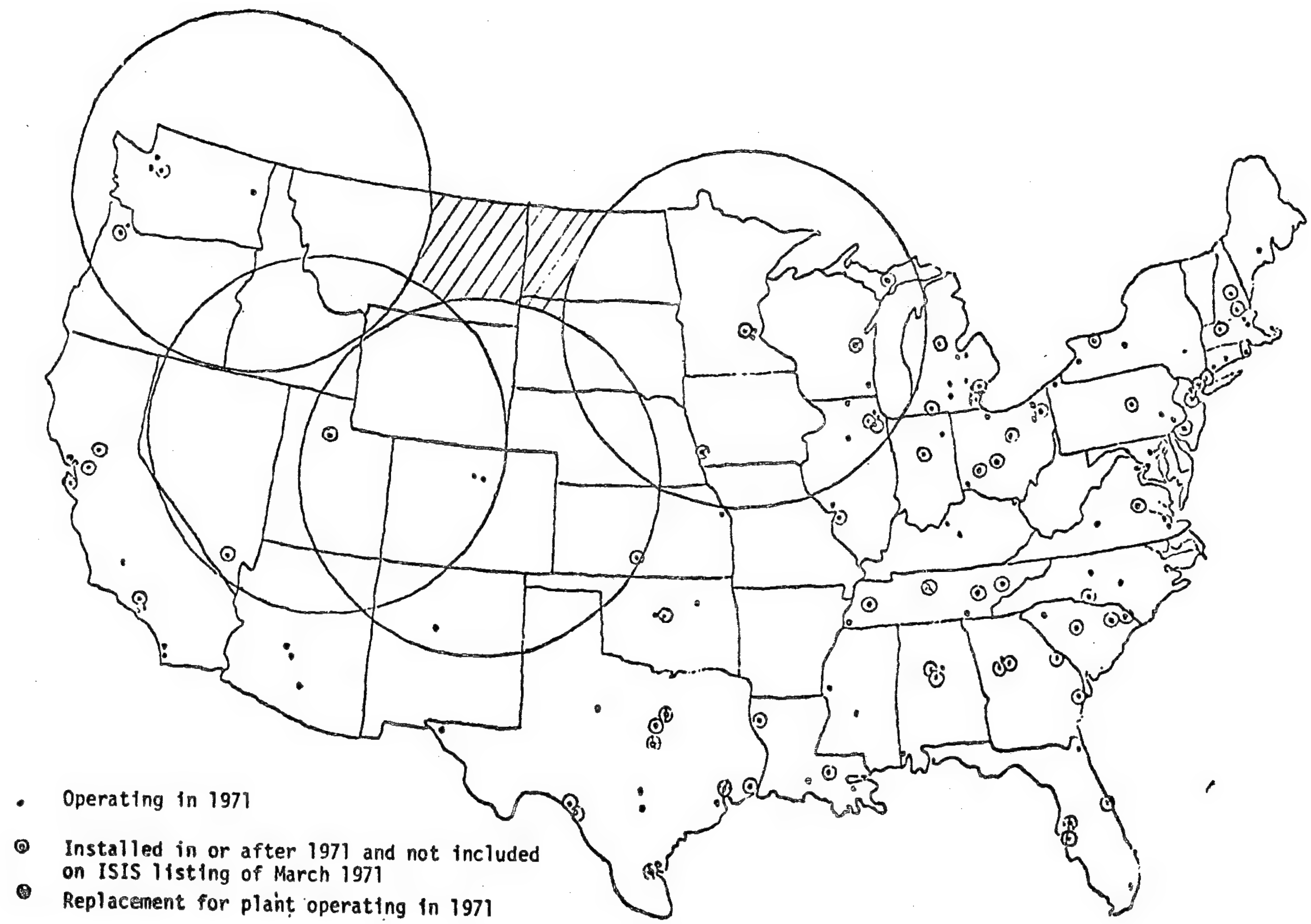


Figure 10. Automobile Recycling Possibilities Via Shredding - 400 Mile Transportation Radius

The indicated shortfall of automobile scrap can be only exacerbated by the changing material composition and decreased size of future automobiles. This is illustrated in Figure 11 where scrap requirements and availability of automobile scrap are compared. Since the average lifetime of an automobile is about 10 years, the full effects will not be felt until the fairly distant future (1990 and beyond).

The prospective shortfall of hulks to supply shredders can evoke the following responses or some combination:

- A more rapid displacement of balers from the auto hulk processing business in favor of shredders.

- An increased utilization of obsolete scrap sources other than automobiles; e.g., large applicances, obsolete industrial machinery.

- A contraction of shredder capacity and increased domination of the industry by larger well-financed operators.

- An effort by larger shredder operators to safeguard their source of supply by long term contracts with auto wreckers, or vertical integration of their operations to include some aspects of the auto wrecking or hulk collection business.

The displacement of balers by shredders will be further reinforced in a climate of competition for auto hulks by the following factors:

- Shredder scrap is of higher quality than baler scrap, commands a significantly higher price, and is more readily accepted by steel mills and foundries as raw materials.

- Hulk preparation for shredding is simpler and less labor intensive than hulk preparation for baling.

- Costs per hulk processed are much lower for shredders than for balers, under typical operating conditions. [5, 6]

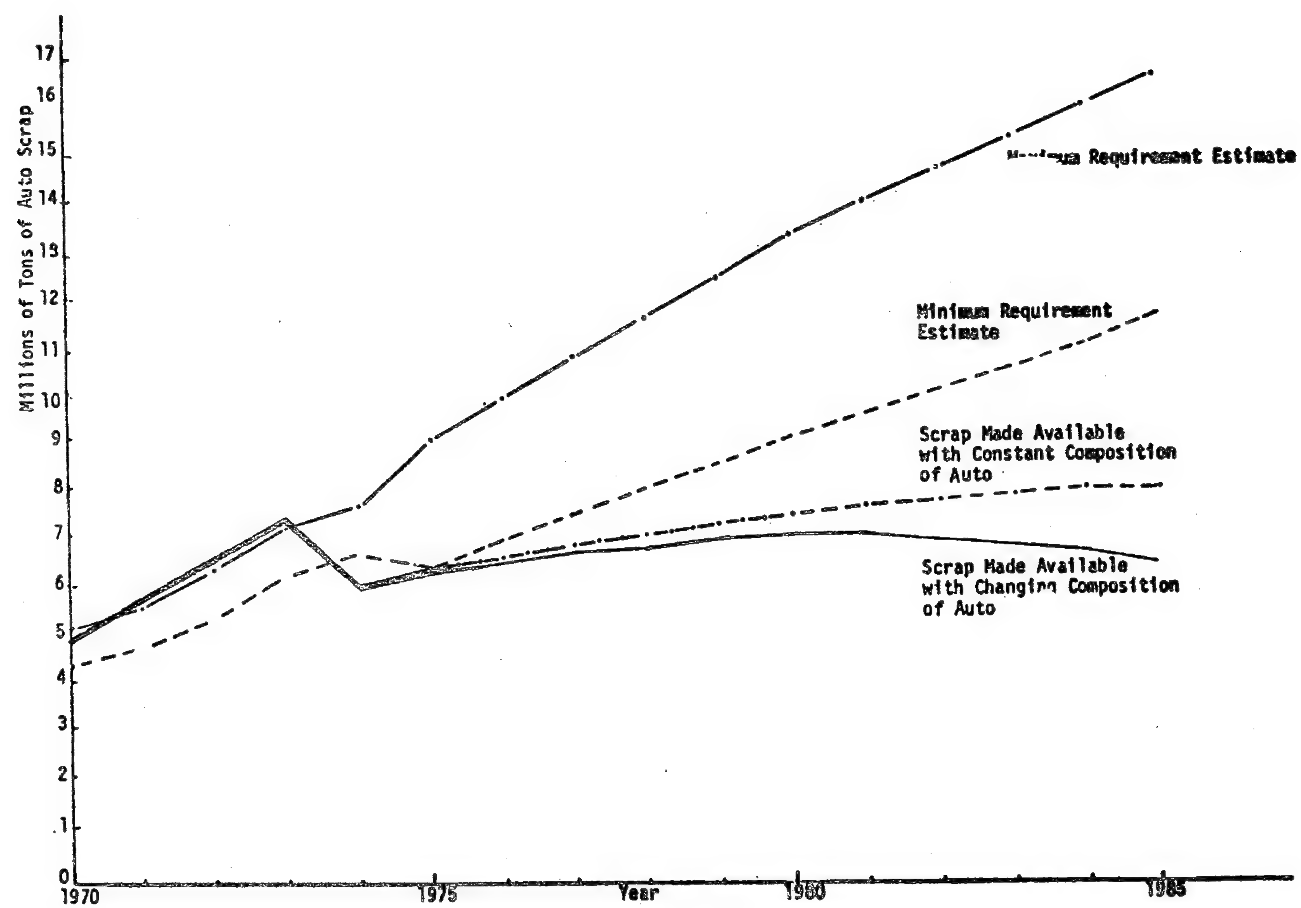


Figure 11. Deregistered Automobiles: Scrap Availability to and Scrap Requirements of Balers and Shredders

The installed capacity of the shredder industry, in terms of the nominal; i.e. claimed, capacity of installed units has been growing rapidly and at about the rate of our projections of demand for shredded scrap, but at a higher absolute level. This is shown in Figure 12. (The difference between the two shredder capacity lines is due to the existence of a few shredders which do not use automobile hulks as input. Automobile shredders use hulks as their primary input but shred other items also

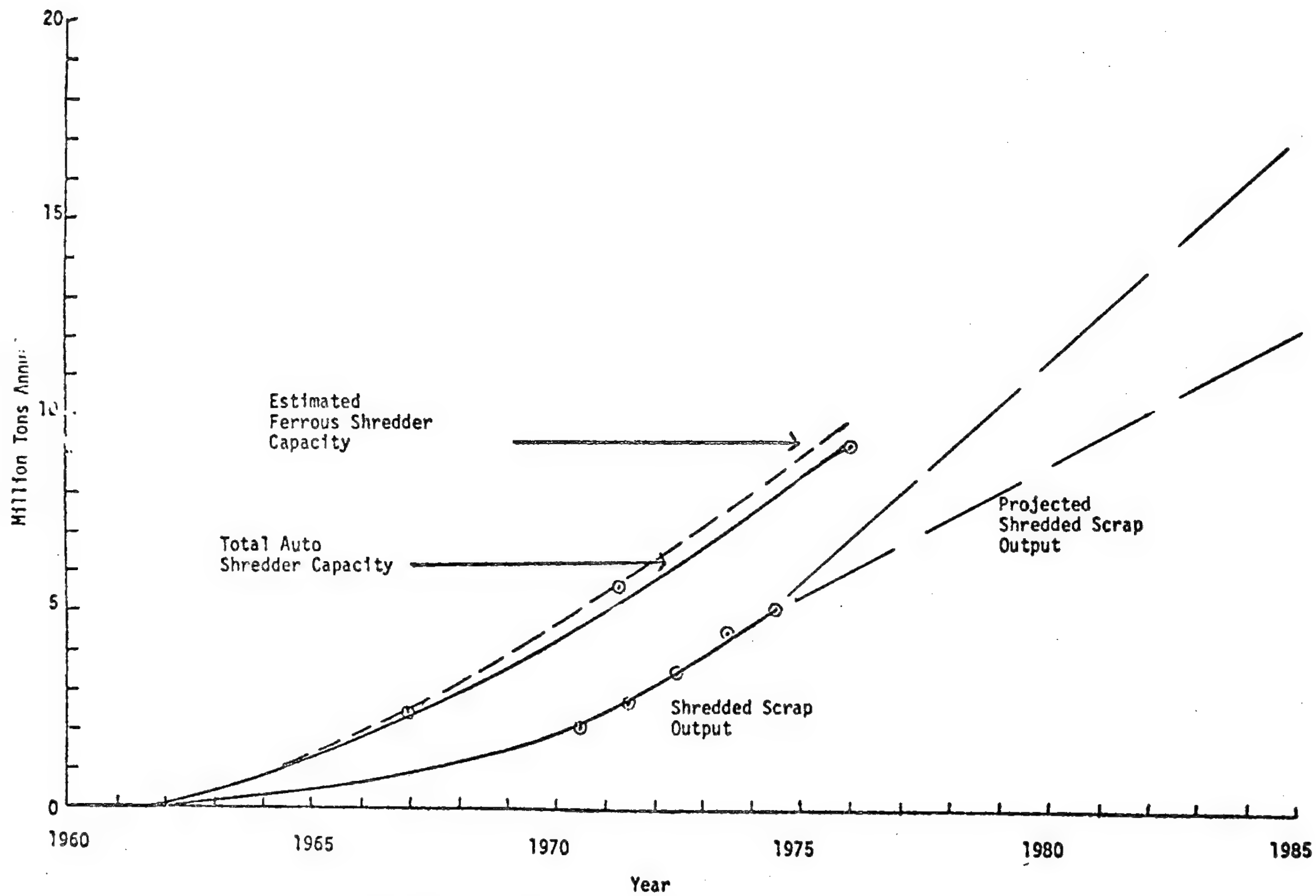


Figure 12. Capacity and Output of Ferrous Shredders

SECTION VI

IMPACT ON NONFERROUS METAL RECYCLING INDUSTRIES

Nonferrous metals recovered from automobiles include lead, copper, zinc and aluminum. Of these, recovered lead is primarily obtained from the storage battery, an easily removed item. Copper is recovered from the radiator, a relatively easily dismantled part provided the car is not being deregistered due to a severe front end collision. Copper wire is distributed throughout the hulk, and is rather difficult to recover economically. Zinc and aluminum are distributed throughout the automobile, mostly in the form of castings.

In Figure 2, we show several routes for nonferrous auto scrap recovery which circumvent the central auto hulk processor. Any nonferrous metal recycling from automobiles which are baled must go through one of these subsidiary circuits since separation after baling is impractical. For automobile hulks which are processed by shredding, some nonferrous output is obtained as mixed metals by magnetic separation from the ferrous output, and air separation from dirt, plastics, fibres, and other waste. The amount of nonferrous mixed metals that will arrive at the shredder output is dependent on both the nonferrous content of the original car, and also on the amount removed by the auto hulk collector and/or the auto wrecker/dismantler. Both of these factors must be considered when assessing the impact of increased aluminum use on shredder operations.

Most shredder operators send their nonferrous fraction to a specialized plant (either their own, if they operate enough shredders to support such a plant, or a plant of one of the larger shredder operators) for segregation into metallic components of sufficient purity to be salable to secondary metals smelters. Usually some heavier pieces of nonmetallic material (e.g., rubber hoses and vibration dampers) escape the air separation process and must also be removed. In some instances, shredder operators have integrated their operations beyond the separation stage and into secondary smelter operations. Thus the larger vertically

integrated operators have a substantial interest in obtaining and processing the nonferrous metal part of automobile hulks.

At the present time, zinc is an important constituent of the nonferrous fraction of shredder outputs. It is generally used in small castings throughout the car where mechanical strength requirements are modest and/or a bright chrome-plated finish is desired. Therefore, hand removal by dismantlers for scrap value is generally uneconomic. Since zinc boils (at 1 atm pressure) at 907°C (compared to 2567°C for copper, 2750°C for iron, and 2467°C for aluminum) it is separable at reasonable purities by distillation. Thus if most aluminum (lighter in weight), copper (different color), and nonmetallics are separated from the nonferrous fraction, the remainder may be rich enough in zinc to be a suitable input to a secondary zinc smelter.

As noted previously, we expect the use of zinc in automobiles to decrease in the coming decade. It is likely to be replaced by platable plastics in decorative functions, and by aluminum or magnesium elsewhere. Our 1990 projections show zinc usage at 1.5% to 3.5% of aluminum usage in a typical automobile.

Copper also will become less and less important as a constituent of the nonferrous fraction of shredder output. Phase out of copper alloy radiators in favor of aluminum would eliminate the single largest copper contributor. We expect copper usage in 1990 automobiles to be in range of 3% to 7% of aluminum usage. As will be shown subsequently, many alloy products of secondary aluminum smelters require copper content in this range. It is possible that separation of copper from aluminum in the nonferrous fraction of shredder output is really unnecessary. However, its distinctive color makes it one of the easier metals to separate by "hand-picking" methods.

Eventually, aluminum is going to be the most important component of the nonferrous fraction of shredder output. With 1980 cars having aluminum content of 11% to 25% by weight of the iron and steel content, the physical volume in 1990 of the aluminum in the nonferrous fraction of shredder output could be 1/3 to 3/4 of the ferrous fraction volume. (We emphasize could because the extent to which aluminum will be separated from a hulk prior to shredding is uncertain.) The major market for this recyclable aluminum is the secondary aluminum smelter industry. A look at the structure of this industry is appropriate.

Considering that aluminum consumption in the U.S. is currently in the 6 million ton per year range and has been above 2 million tons per year for the last 20 years, the amount of aluminum that is recovered annually from old scrap is surprisingly small - about 200,000 tons in 1973. The data in Table 22 shows the relationship of recovery from old scrap to total consumption since 1967. Clearly, great amounts of aluminum are being stored in our environment. The amounts of old aluminum scrap that could become available from retired automobiles in 1990 is on the order of 1 to 2 million tons or about 8% to 15% of expected total consumption in 1990. Utilization of this much old scrap by the secondary aluminum industry would require an expansion of secondary production relative to primary production, and/or a greater use of old scrap relative to new scrap than is current practice in the secondary aluminum industry.

The principal product of the secondary aluminum industry is casting alloys. However, casting alloys comprise less than 20% of total aluminum consumption, the remainder being mostly wrought alloys. For various technical reasons, to be discussed subsequently, the secondary aluminum industry does not presently compete with primary producers in the wrought alloys market. This, even though their raw materials (old and new scrap) must be mostly wrought alloys, since wrought alloys are used in aluminum products at a 5 to 1 ratio to casting alloys. We thus

TABLE 22

U.S. ALUMINUM CONSUMPTION STATISTICS

(Thousands of Short Tons)

Year	Total Consumption	Recovery from New Scrap	Recovery from Old Scrap	Old Scrap as % of Total
1973	5685.3	842.0	196.5	3.5
1972	5588.3	755.8	188.6	3.4
1971	5099.0	648.1	167.0	3.3
1970	4518.5	635.8	145.6	3.2
1969	4710.4	752.6	148.2	3.2
1968	4603.4	662.2	154.7	3.3
1967	4008.6	569.3	128.5	3.2

Source: Reference #41.

have the preponderant flow of materials being from the primary metal producers into wrought alloy products and new scrap, then to secondary metal producers and into casting alloy products. An increase in secondary metal production relative to primary metal production thus implies either an increase in the use of casting alloys relative to wrought alloys or a need for secondary producers to enter the wrought alloys market. (Of course, at least a decade is available for the adjustments to be made.) The recent history of secondary aluminum recovery and its relationship to wrought alloy and casting alloy production is shown in Table 23.

As a consumer of aluminum the automobile industry is presently rather inverted from the remainder of the economy, using preponderantly casting alloys. However, the trend in recent years has been toward greater use of wrought products. Future use of aluminum in automobiles will be heavily into sheet metal body parts, and structural members such as bumpers and frames. These will require wrought aluminum alloys. We estimate that of the increased aluminum in automobiles in 1980 and 1990, relative to 1975, two-thirds of the increase will be in wrought alloys. Table 24 shows some recent history of shipments to the automobile industry and our estimate for 1980 and 1990 for the maximum aluminum automobile scenario. For other scenarios, the shift to wrought versus cast alloys will be less severe but still pronounced. The expected response to the combined stimuli of increased old aluminum scrap availability (from retired autos) and a decrease in demand for cast alloys relative to wrought alloys is increased secondary production, relative to primary production, and some penetration by the secondary producers into the wrought alloy market, provided the technical difficulties of producing wrought alloys from secondary sources, particularly old scrap, can be overcome.*

*If a very high degree of segregation of old scrap of a particular wrought alloy can be achieved, production of that wrought alloy from scrap would, of course, be possible. The best example would be aluminum beverage cans, the collection of which is currently being subsidized by the primary aluminum producers.

TABLE 23

PROFILE OF SECONDARY ALUMINUM RECOVERY INDUSTRY

(Thousands of Short Tons)

	Scrap Consumption by Primary Producer and Others		Scrap Consumption by Secondary Smelters		Total U.S. Industry Shipments		Shipments by Secondary Smelters		
Year	Old	New*	Old	New*	Wrought Alloys	Casting Alloys	Casting Alloys	All Other**	% of Total Cast
1973	64.6	461.1	111.8	625.0	5450.7	1013.0	576.0	196.2	56.7
1972	34.1	411.8	117.7	588.8	4604.6	927.8	533.4	149.6	57.5
1971	19.5	345.3	118.4	521.5	3923.1	788.6	466.8	145.3	59.3
1970	10.5	311.8	125.6	524.7	3693.1	752.6	448.8	132.9	59.6
1969	8.8	336.2	110.1	608.2	3826.4	849.0	506.7	123.7	59.7
1968	8.5	307.4	113.9	585.4	3585.0	794.1	491.2	140.4	61.9
1967	21.2	244.5	103.8	513.3	3175.0	767.4	443.4	130.8	57.8

* So-called "Sweated Pig" included with new scrap

** Includes 97% "pure" Al, deoxidizers, and other uses.

Source: Reference #41.

TABLE 24

AUTOMOBILE INDUSTRY CONSUMPTION OF ALUMINUM

(Thousands of Short Tons)

Year	Mill Products (Wrought Alloys)	Ingot (Casting Alloys)	Cast/Wrought Ratio	Auto Castings as % Total Castings
1967	103.5	363.5	3.51	47.4
1968	125	399.5	3.19	50.3
1969	133.5	399.5	2.99	47.0
1970	112.5	328	2.91	43.6
1971	150	411	2.74	52.2
1972	190	460	2.45	50.1
1973	271	588.5	2.17	58
1975*	270	540	2	---
1980*	1580	1220	0.77	---
1990*	3600	2210	0.61	---

*Estimates based on 9×10^6 units manufactured in 1975, 10×10^6 in 1980, and 12×10^6 in 1990, and maximum aluminum automobile scenario.

Source: 1967 - 1973 data, Reference # 45 .

The difficulty in producing wrought alloys from secondary sources is made evident by a comparison of specifications for wrought and cast alloys, as shown in Table 25. The important differences from a recycling standpoint are:

> The low tolerance of wrought alloys for iron and silicon versus the large requirements for silicon and high tolerance for iron of casting alloys.
>
> The high percentage of copper required in many alloys, both wrought and casting.
>
> The relatively large tolerance for zinc of some casting alloys and the large zinc requirement of the high strength wrought alloy 7178.

The relatively large impurity tolerances of casting alloys, particularly for iron and zinc, is the reason that secondary smelters prefer to make casting alloys. Neither dissolved iron nor zinc can be separated from a melt of aluminum scrap by any economically feasible process. The only way to lower the iron or zinc content is to dilute the melt with scrap that is known to be low in these elements. New scrap purchased from a fabricator or pure aluminum purchased from a primary producer are the only likely sources of material with a known and suitable composition for dilution.

The general run of old and new scrap used by a secondary smelter is probably a 5 to 1 mix of wrought alloy and casting alloy, as in fabricated products. As such, it is probably too rich in iron (screws, etc.) to go into a wrought alloy and deficient in silicon and/or copper for the casting alloys. Hence, secondary smelters must purchase much copper scrap and metallurgical silicon, at prices well above aluminum scrap. Therefore they would probably welcome a mixed scrap of high silicon and copper content, but low in iron and zinc content for their casting alloy business. In order to divert part of their output to

TABLE 25

COMPOSITIONS OF SOME ALUMINUM ALLOYS

	Major Alloying Elements (% Range)				Major Impurities (% Max)					
Wrought Alloys	Silicon	Copper	Magnesium	Zinc	Iron	Silicon	Copper	Magnesium	Zinc	
2036	-	2.2-3	.3-.6	-	.5	.5	-	-	.25	Reynolds Car
6061	0.4-0.8	.15-.4	0.8-1.2	-	.7	-	-	-	.25	High Strength Alloys
7178	-	1.6-2.4	2.4-3.1	6.3-7.3	.7	.5	-	-	-	High Strength Alloys
Casting Alloys										
380/A380	7.5-9.5	3-4	-	-	2	-	-	.1	1/3	Most widely used
390	16-18	4-5	.45-.65	-	1.3	-	-	-	.1	Vega Block
360	9-10	-	.4-.6	-	2	-	.6	-	.5	Intricate Casting
F132	8.5-10.5	2-4	.5-1.5	-	1.2	-	-	-	1.0	Auto Piston
356	6.5-7.5	-	.2-.4	-	.6	-	.2	-	.3	Auto transmission Cases

Source: Reference #27.

wrought alloys, they would probably prefer a scrap free from casting alloys and where some extra effort has been made to reduce iron content; e.g., finer shredding and additional magnetic separation to get rid of the screws, bolts, and nuts.

The nonferrous metal fraction of cars now being shredded (1965 model vintage) probably consists of almost equal proportions of aluminum and copper with larger amounts of zinc.[8] Hence,it is of little value without extensive separation. We have found most operators of separation plants to be reluctant to discuss the particular methods they use but we surmise that the processing may include additional shredding and magnetic separation, screening (eliminates small pieces and facilitates succeeding steps), washing (to bring out distinctive colors), and hand sorting. Use of sink-float (i.e.,"heavy-media" separation) separation methods, so-called "aluminum magnet" devices, and devices which exploit the ballistic characteristics of particles (generally called "elutriators or classifiers") is widely discussed but no reliable indication of the extent to which they are actually in use could be obtained. The Bureau of Mines has an extensive reserach program[46] on such devices at their Salt Lake City research center and other places, but were unable to provide estimates on the extent of their commercial application.

When 1980 vintage cars are entering the resource recovery cycle, about 1987 to 1990, the zinc content of the nonferrous metal output of shredders will be small relative to the aluminum content but probably not small enough to completely ignore. Rejection of most of the zinc from the nonferrous metal shredder output, along with residual nonmetallic pieces, may be the prime concern. Retention of the small copper content of the nonferrous output with the aluminum may be advantageous. This suggests that exploitation of the lower melting point of zinc (419°C) relative to aluminum (660°C) or copper (1083°C) may become a preferred separation technique. Part of the heat required

could be provided by the nonmetallics (plastics, rubber) that accompany the nonferrous fraction or that appear in the waste fraction.

In order to obtain an aluminum scrap from auto hulks that would be a suitable raw material for wrought alloy production, it is probable that some separation of wrought alloys would be necessary before shredding. Hand removal of hang-on parts like hoods and trunk lids should be relatively easy but iron contamination or admixture of casting alloys from latches, hinges and springs may be a problem. Actual operating procedures in the resource recovery industries will develop as the economic factors warrant.

Aluminum engine blocks of the Vega type (390 alloy in Table 25) may become relatively valuable scrap items because of the high silicon content. Metallurgical grade silicon is currently more expensive than primary aluminum. A large, easily recognized aluminum alloy object of known composition and high silicon content should bring a premium price in the aluminum scrap market. It may pay for the labor for removal and disassembly of the engine to market the block separately.

SECTION VII

INTEGRATED ANALYSIS OF THE IMPACT OF AUTOMOBILE COMPOSITION CHANGES USING THE STRATEGIC ENVIRONMENTAL ASSESSMENT SYSTEM

BRIEF DESCRIPTION OF SEAS

The Strategic Environmental Assessment System (SEAS) is a collection of interdependent models which were created by the Environmental Protection Agency in order to forecast the state of the environment and the economic impacts of pollution control. The system is modular in nature, consisting of 28 computational and input/output computer programs which are associated with 13 modules. These modules are illustrated in Figure 13. Each module can be run independently (assuming the data base has been generated by a preceding module if necessary). The shaded modules in the diagram were used for this study. They were chosen as the most significant modules for the analysis.

INFORUM: The INFORUM model is a macroeconomic model, linked to an input-output model, which was created by Clopper Almon of the University of Maryland. It makes annual forecasts in constant dollars to 1985 of the output of 185 commercial, industrial and agricultural sectors which comprise the entire U.S. economy. A sample of the output follows (Table 26). Outputs are expressed in constant 1971 dollars, which is the "base year" for INFORUM. (Our detailed study of auto composition used 1975 as the base year since data on auto composition was most readily available for that year. The parameters for automobile industry purchases were adjusted to the newer data.)

SECTOR DISAGGREGATION: This module subdivides the economy into approximately 350 additional sectors, by techniques developed at IR&T to provide more detail in the industrial sector so that pollution loadings could be more accurately forecast. The output of this module is provided in Table 27.

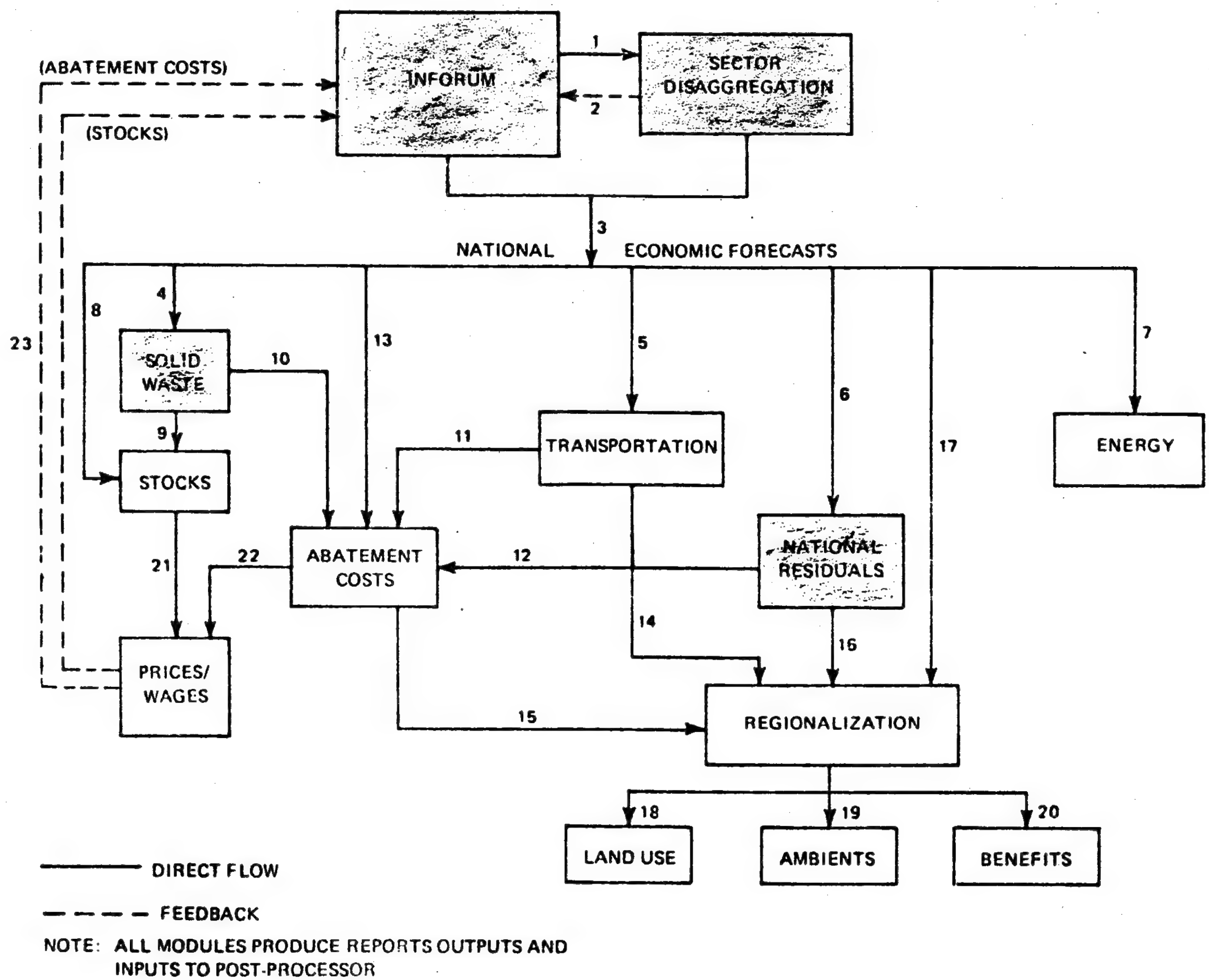


Figure 13. SEAS System Flow Chart

TABLE 26

SCENARIO COMPARISON FOR INFORUM

SCENARIO 1: NATIONAL ECONOMIC MODEL - ALMON BASE SCENARIO

TOTAL OUTPUT

NUMBER		NAME	YEAR 1983 OUTPUT (M$) S1	YEAR 1983 S1 ---% TS1	YEAR 1983 RANK	YEAR 1985 OUTPUT (M$) S1	YEAR 1985 S1 ---% TS1	YEAR 1985 RANK
81	0	CEMENT, CONCRETE, GYPSUM	0.1124E+05	0.43	54	0.1176E+05	0.43	54
82	0	OTHER STONE + CLAY PRODUCTS	0.6041E+04	0.23	90	0.6310E+04	0.23	91
83	0	STEEL	0.3167E+05	1.22	19	0.3162E+05	1.15	20
84	0	COPPER	0.1020E+05	0.39	59	0.1026E+05	0.37	62
85	0	LEAD	0.7028E+03	0.03	176	0.7124E+03	0.03	176
86	0	ZINC	0.6881E+03	0.03	177	0.7097E+03	0.03	177
87	0	ALUMINUM	0.1079E+05	0.42	57	0.1136E+05	0.41	56
88	0	OTH PRIM NON-FER METALS	-.9640E+03	-0.04	185	-.2388E+04	-0.09	185
89	0	OTH NON-FER ROLL + DRAW	0.1435E+04	0.06	162	0.1466E+04	0.05	164
90	0	NON-FERROUS WIRE DRAWING	0.5320E+04	0.20	99	0.5508E+04	0.20	100
91	0	NON-FER CASTING AND FORGING	0.1533E+04	0.06	160	0.1527E+04	0.06	160
92	0	METAL CANS	0.5331E+04	0.21	98	0.5540E+04	0.20	99
93	0	METAL BARRELS AND DRUMS	0.6586E+03	0.03	178	0.6850E+03	0.03	178
94	0	PLUMBING AND HEATING EQUIP.	0.2283E+04	0.09	145	0.2332E+04	0.09	145
95	0	STRUCTURAL METAL PRODUCTS	0.1911E+05	0.74	34	0.2023E+05	0.74	34
96	0	SCREW MACHINE PRODUCTS	0.3762E+04	0.14	123	0.3315E+04	0.14	123
97	0	METAL STAMPINGS	0.9996E+04	0.39	60	0.1037E+05	0.38	59
98	0	CUTLERY, HAND TOOLS, HARDWR	0.6519E+04	0.25	88	0.6757E+04	0.25	88
99	0	MISC FABRICATED WIRE PRODUCT	0.2712E+04	0.10	135	0.2781E+04	0.10	138
100	0	PIPES, VALVES, FITTINGS	0.5136E+04	0.20	103	0.5406E+04	0.20	103
101	0	OTH FABRICATED METAL PRODUCT	0.5780E+04	0.26	84	0.7132E+04	0.26	83
102	0	ENGINES AND TURBINES	0.8318E+04	0.32	72	0.8990E+04	0.33	70
103	0	FARM MACHINERY	0.4413E+04	0.17	114	0.4570E+04	0.17	114
104	0	CONSTR, MINING, OIL FIELD MA	0.8905E+04	0.34	67	0.9384E+04	0.34	66
105	0	MATERIALS HANDLING MACH	0.5097E+04	0.20	104	0.5389E+04	0.20	104
106	0	MACHINE TOOLS, METAL CUTTING	0.3032E+04	0.12	131	0.3175E+04	0.12	131
107	0	MACHINE TOOLS, METAL FORMING	0.1262E+04	0.05	169	0.1278E+04	0.05	168
108	0	OTHER METAL WORKING MACHINER	0.7252E+04	0.28	81	0.7443E+04	0.27	80
109	0	SPECIAL INDUSTRIAL MACHINERY	0.8550E+04	0.33	70	0.8640E+04	0.32	73
110	0	PUMPS, COMPRESSORS, BLOWERS	0.4573E+04	0.18	113	0.4743E+04	0.17	113
111	0	BALL AND ROLLER BEARINGS	0.2406E+04	0.09	143	0.2535E+04	0.09	142
112	0	POWER TRANSMISSION EQUIPMENT	0.1965E+04	0.08	151	0.1965E+04	0.07	155
113	0	INDUSTRIAL PATTERNS	0.2438E+04	0.09	142	0.2490E+04	0.09	143
114	0	COMPUTERS AND RELATED MACHIN	0.2092E+05	0.81	32	0.2187E+05	0.80	31
115	0	OTHER OFFICE MACHINERY	0.1964E+04	0.08	152	0.1992E+04	0.07	154
116	0	SERVICE INDUSTRY MACHINERY	0.1388E+05	0.53	47	0.1496E+05	0.55	45
117	0	MACHINE SHOP PRODUCTS	0.8971E+04	0.35	66	0.9715E+04	0.35	63
118	0	ELECTRICAL MEASURING INSTRUM	0.2078E+04	0.08	149	0.2178E+04	0.08	149
119	0	TRANSFORMERS AND SWITCHGEAR	0.5948E+04	0.23	92	0.6363E+04	0.23	90
120	0	MOTORS AND GENERATORS	0.4833E+04	0.19	108	0.5084E+04	0.19	109

TABLE 27

SCENARIO COMPARISON FOR INFORUM

SCENARIO 1: NATIONAL ECONOMIC MODEL - ALMON BASE SCENARIO

OUTPUT SUBSECTORS

NUMBER		NAME	YEAR 1983 S1	YEAR 1983 S1/TS1 %	YEAR 1983 RANK	YEAR 1985 S1	YEAR 1985 S1/TS1 %	YEAR 1985 RANK
69	3	INDUST COMBUST OF NAT GAS TRIL BTU	0.1228E+04			0.1169E+04		
69	4	CRUDE OIL REFINING MIL BBLS	0.6005E+04			0.6340E+04		
69	5	JET FUEL PRODUCTICN MIL BBLS	0.8781E+03			0.9690E+03		
69	6	GASOLINE PRODUCTION MIL BBLS	0.3280E+04			0.3525E+04		
69	30	REFINER W/CATALYTIC CRACKING MIL BBLS	0.1777E+04			0.1877E+04		
69	31	REFINER W/O CATALYTIC CRACK MIL BBLS	0.4227E+04			0.4463E+04		
69	32	TOPPING PLANTS MIL BBLS	0.3063E+03			0.3233E+03		
69	33	REFINERIES W/CRACKING MIL BBLS	0.5699E+04			0.6016E+04		
69	34	CRACKING(NO PETRO OR LUBES) MIL BBLS	0.2547E+04			0.2689E+04		
69	35	PETROCHEM(CRACKING,NO LUBES) MIL BBLS	0.9517E+03			0.1005E+04		
69	36	LUBE OIL(CRACK,NO PETRCCHEM) MIL BBLS	0.1539E+04			0.1624E+04		
69	37	INTEGRAT(CRACK.LUBE,PETROCH) MIL BBLS	0.6610E+03			0.6979E+03		
71	1	ASPHALT MIL TCNS	0.5066E+03			0.5082E+03		
72	1	TIRES AND INNER TUBES MIL TONS	0.4152E+01			0.4416E+01		
73	1	RUBBER RECLAIMING MIL TONS	0.4309E+00			0.4553E+00		
73	2	LATEX MANUFACTURE MIL TONS	0.7923E+00			0.8214E+00		
75	1	LEATHER TANNING MIL TONS	C.8288E+00			0.7758E+00		
75	30	CHRCME TANNING MIL TONS	0.6224E+00			0.5826E+00		
75	31	OTHER TANNING MIL TCNS	0.2064E+00			0.1932E+00		
75	32	PULP HAIR/CHRCME TANNING MIL TONS	0.3498E+00			0.3274E+00		

NATIONAL RESIDUALS: This module links pollution loadings to outputs of sectors. The pollution loadings forecast the level of pollution abatement control equipment which is being applied to each sector. Gross pollution refers to pollution loadings which would occur if no control technology were instituted. Net pollution loading is the actual emissions to the environment. A sample output is presented in Table 28.

SOLID WASTE: The solid waste module estimates both the quantity of solid waste generated, and the level of recycling in a manner consistent with the national economic forecasts provided by INFORUM. A sample of the solid waste model is presented in Table 29.

METHODOLOGY: Four scenarios were constructed and implemented in the SEAS model. They were:

(1) No change in materials composition of the automobile from the 1971 level

(2) Most probable car

(3) Maximum credible aluminum car

(4) Maximum credible plastic car.

The projected cases, (2), (3) and (4), were based on our automobile materials composition study summarized in Section II. They reflect the possible options for substitution of aluminum and plastic for iron and steel and copper in the trend toward smaller and lighter vehicles which consume less fuel and materials resources. A base case, (1) above, was run in the model to allow comparison with a no materials substitution scenario.

The scenarios were implemented by changing the technical coefficients (A matrix element) in the INFORUM model. Each technical coefficient represents the value of material purchases required per dollar of output of a given industrial sector. In this case, the revised coefficients represented the projected required purchases of ferrous metals, aluminum, plastics, and copper, by the automobile industry, for the three cases: most probable, maximum credible aluminum and maximum credible plastic automobile.

TABLE 28

RESIDUAL BY SECTOR: 1985

SECTOR / SUBSECTOR	RESIDUAL CATEGORY / RESIDUAL COMPONENT	TAX-ONOMY	GROSS	CAPTURED	NET	RECYCLED	UNRECYCLED
	(S) PARTICULATES	11152	.2158E+07	.0	.2158E+07		
	(S) NON-COMBUSTIBLE SOLID WASTE	31252	.4987E+07	.0	.4987E+07		
31 CEMENT - DRY GRINDING	(P) PARTICULATES	11222	.1175E+08	.7754E+07	.3994E+07	.0	.1175E+08
	(S) PARTICULATES	11152	.2342E+07	.0	.2342E+07		
	(S) NON-COMBUSTIBLE SOLID WASTE	31252	.5412E+07	.0	.5412E+07		
82 OTHER STONE + CLAY PRODUCTS							
1 ASBESTOS PRODUCTS	(P) PARTICULATES						
	(P) ASBESTOS	11223	.5195E+06	.4411E+06	.7845E+05	.0	.5195E+06
	(P) BIOCHEMICAL OXYGEN DEMAND	21222	487.1	368.8	118.3	.0	487.1
	(P) CHEMICAL OXYGEN DEMAND	21222	.9336	.3155E-01	.9020	.0	.9336
	(P) SUSPENDED SOLIDS	21222	.1009E+05	8826.	1261.	.0	.1009E+05
	(P) DISSOLVED SOLIDS	21222	.1689E+05	.0	.1689E+05	.0	.1689E+05
	(P) BASES	21222	8970.	4216.	4754.	.0	8970.
2 CRUSHED STONE	(P) PARTICULATES	11222	.1116E+08	.2232E+07	.8927E+07	.0	.1116E+08
3 SAND AND GRAVEL	(P) PARTICULATES	11222	.6577E+05	.0	.6577E+05	.0	.6577E+05
83 STEEL	(P) PARTICULATES	11222	.1179E+07	.2652E+06	.9134E+06	.0	.1179E+07
	(S) PARTICULATES	11152	.7160E+05	.0	.7160E+05		
	(S) SUSPENDED SOLIDS	21252	.1883E+05	.0	.1883E+05		
	(S) NON-COMBUSTIBLE SOLID WASTE	31252	.1671E+06	.0	.1671E+06		
	(S) INDUSTRIAL SLUDGES	31252	7691.	.0	7691.		
	(P) SUSPENDED SOLIDS	21222	.6451E+06	.1901E+06	.4551E+06	.0	.6451E+06
	(S) INDUSTRIAL SLUDGES	31252	.4390E+05	.0	.4390E+05		
	(P) DISSOLVED SOLIDS						
	(P) CHROMIUM	21222	126.5	101.4	25.07	.0	126.5
	(P) FERROUS METALS	21222	.3343E+06	.4683E+05	.2874E+06	.0	.3343E+06
	(P) FLUORINE	21222	474.4	400.1	74.28	.0	474.4
	(P) OIL AND GREASES	21222	.9171E+05	.6930E+05	.2241E+05	.0	.9171E+05
	(S) INDUSTRIAL SLUDGES	31252	.5474E+05	.0	.5474E+05		
	(P) WASTE WATER	21222	.5205E+07	.3633E+06	.4842E+07	.0	.5205E+07
1 INDUST COMBUST OF COAL	(P) PARTICULATES	11122	.5463E+06	.3289E+06	.2174E+06	.0	.5463E+06
	(S) PARTICULATES	11152	.9932E+05	.0	.9932E+05		
	(S) NON-COMBUSTIBLE SOLID WASTE	31252	.2295E+06	.0	.2295E+06		

*** ALL RESIDUALS IN TONS EXCEPT WASTE WATER (MILLION GALLONS),
RADIONUCLIDES (CURIES),
THERMAL LOADING (TRILLIONS OF BTUS)

TABLE 29

SOLID WASTE AND RECYCLING

RECYCLED MATERIAL REPORT *

RECYCLED MATERIAL (THOUSANDS OF TONS)	1980	1981	1982	1983
ALUMINUM	2160.(.291)	2361.(.310)	2277.(.295)	2525.(.320)
COPPER	1779.(.434)	1864.(.448)	1854.(.445)	1848.(.440)
FERROUS METALS	46886.(.370)	47969.(.380)	48946.(.393)	50032.(.404)
GLASS	2272.(.083)	2370.(.084)	2466.(.086)	2569.(.087)
LEAD	846.(.648)	858.(.648)	885.(.664)	912.(.677)
PAPER	8372.(.207)	8603.(.208)	8813.(.210)	9042.(.212)
PLASTICS	511.(.033)	524.(.033)	535.(.033)	548.(.033)
RUBBER	699.(.150)	740.(.153)	792.(.159)	842.(.163)
TEXTILES	893.(.113)	896.(.111)	924.(.113)	962.(.115)
WOOD	7656.(.090)	7645.(.089)	7612.(.088)	7620.(.088)
ZINC	362.(.216)	372.(.219)	375.(.220)	382.(.221)
PAPERBOARD & CONSTRUCTION	11144.(.302)	11613.(.309)	12058.(.316)	12556.(.323)

**** THE VALUE IN PARENTHESES REPRESENTS THE PERCENTAGE OF TOTAL MATERIAL RECYCLED

*Total amount of scrap recycled (prompt and obsolete) and fraction of total material demand derived from recycled scrap.

The change from the base case in the material requirements per automobile for 1980 and 1985 was computed based on the estimates made for each case. This fraction was then used to revise the appropriate "A" matrix coefficients currently in the model. Not only direct sales of materials to the automobile industry were taken into account, but also sales of materials through intermediate industries; i.e., the sales of iron and steel to metal stampings, which produce body fenders for automobiles. Revised coefficients approximated nearly all of the direct and indirect sales of materials to the motor vehicle industry. All other "A" coefficients as projected in the input-output table were left unchanged. Also, projections of total output of the motor vehicle industry made by the model were not changed.

The second change made in the model was that the average miles per gallon for automobiles projected to be on the road in 1985 was computed to take into account the fuel savings of the smaller and lighter automobiles. The revised miles per gallon figure was applied to the vehicle miles travelled forecast in the SEAS transportation model to obtain an estimate of savings in gasoline consumption. This was reflected in reduced consumer demand for gasoline in the final demand part of the INFORUM model.

Another assumption was that any decline in the demand for petroleum from reduced gasoline consumption was reflected in decreased imports of crude petroleum.

<u>RESULTS</u>: The INFORUM module provided economic and energy results, the RESIDUAL module provided air/water pollution results and SOLID WASTE provided results on solid waste generation, recycling levels and scrap availability. Each of these results will be discussed separately.

The primary conclusion of the economic analysis is that in spite of the fact that the automobile industry is the largest sector of the economy, the overall impact of major changes in material requirements for the industry is minimal. This fact is demonstrated in Table 30 where the projected aggregate economic statistics for each scenario are

TABLE 30

COMPARISON OF AGGREGATED ECONOMIC STATISTICS FOR 1985

Scenario 1: National Economic Model - No Change in Auto Composition Base Case
Scenario 2: National Economic Model - Most Prob Change in Automobile Composition Case
Scenario 3: National Economic Model - Maximum Credible Aluminum
Scenario 4: National Economic Model - Maximum Credible Plastic

Name	Units	S1	S2	$\frac{S2 - S1}{S1}$ %	S3	$\frac{S3 - S1}{S1}$ %	S4	$\frac{S4 - S1}{S1}$ %
Total Employment	(M)	103.3	103.1	-0.18	103.1	-0.19	103.1	-0.16
Civilian Unemployment Rate	(%)	4.221	4.395	4.12	4.407	4.40	4.373	3.59
Per Capita GNP	($)	7,653	7,645	-0.11	7644.	-0.11	7646	-0.09
Exports	(M$)	124,400	124,000	-0.27	124,000	-0.30	124,200	-0.16
Imports	(M$)	-131,600	-128,100	-2.65	-127,700	-2.95	-127,800	-2.88
Personal Consumption Expend.	(M$)	1,192,000	1,188,000	-0.34	1,188,000	-0.38	1,188,000	-0.33

compared. The unemployment rate slightly increases, imports decrease, and all other statistics remain about the same. One interesting result is that the unemployment resulting from decreases in production of the primary industries, steel and petroleum refining, industries directly related to the automobile industry, is less significant than unemployment resulting from secondary sectors of the economy indirectly related to the automobile industry. This can be seen in Table 31.

The individual industries most affected were those directly related to the automobile industry; i.e., petroleum refining, iron and steel, aluminum, and plastics. The impacts of changing the composition of the automobile damp out rather quickly and those industries which are more than two steps removed from the automobile industry are not usually affected by more than 1%. This is illustrated in Figure 14 which links the industries affected by the substitutions into a sequence of sales for scenario (3), the maximum aluminum car as compared to the base case.

Two other major economic conclusions can be derived from this integrated analysis which were not evident prior to the running of SEAS:

(1) Even though plastic sales to automobiles in the maximum plastics scenario increases 260% per car in 1985 over the base scenario, overall plastics output is only 3.43% greater than the base scenario in 1985. The model thus indicates that the sale of plastics to other industries is growing so rapidly as to overwhelm the increasing sales of plastics to automobiles.

(2) In the maximum aluminum car scenario (3), 4.4 x 10^{15} BTU's of energy are saved over the base case scenario (1). The SEAS models, in conjunction with other sources, provide an estimate on how this savings is achieved.

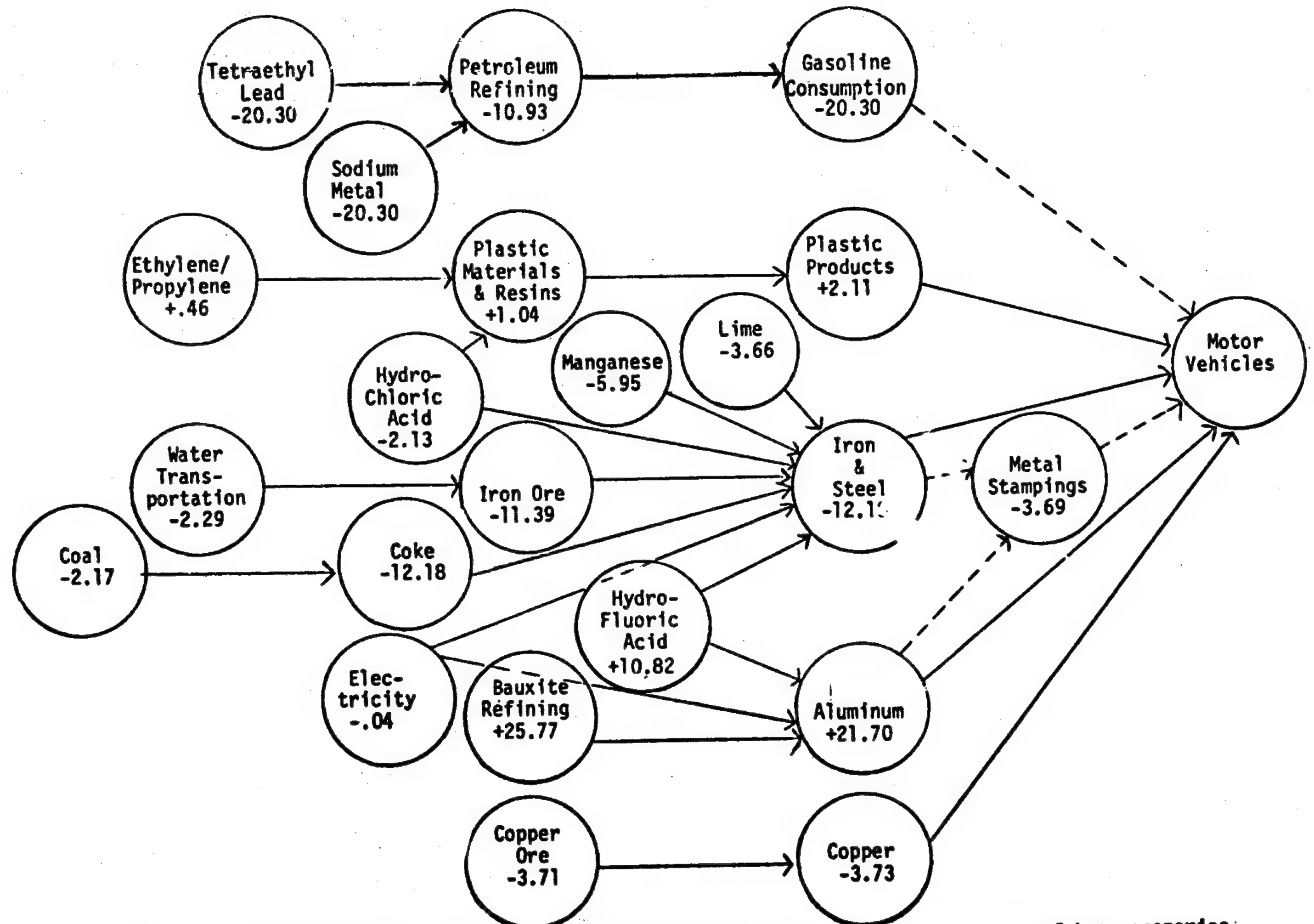
TABLE 31

EMPLOYMENT IMPACTS FOR THE MAXIMUM ALUMINUM CAR

	S1	S3	S3 - S1
PRIMARY IMPACTED INDUSTRIES			
Steel and Iron	757,500	665,200	- 92,300
Petroleum Refining	206,800	186,000	- 20,800
Nonferrous Metals	343,000	389,000	+ 46,000
Plastics	298,000	304,000	+ 6,000
Metal Stampings	439,900	428,500	- 11,400[a]
SECONDARY IMPACTED INDUSTRIES[b]	105,214,800	105,127,300	- 87,500
TOTAL	107,260,800	107,100,000	-165,000

[a]This estimate may be too high because the model makes projections in terms of dollar value. Lighter cars will use lighter and smaller stampings with less value, but this does not necessarily mean that fewer employees will be required to produce them.

[b]The secondary impacted industry most affected is mining with a decrease of 5,000 jobs of 1.6%.



*The values in the circles represent the total decreases in outputs as percentages of base scenarios.

Figure 14. Partial Flow Analysis of Materials Inputs* to the Automobile Industry in the Max Aluminum Car Scenaric

81.6% (3.6×10^{15} BTUs) of this savings is achieved as a result of reduced gasoline consumption, resulting from a higher miles per gallon. 6.3% ($.28 \times 10^{15}$ BTUs) is attributable to savings in automobile production and 12.1% ($.537 \times 10^{15}$ BTUs) from general reductions in the economy.

POLLUTION ANALYSIS: The impacts of the material substitutions on the environment reflect to a certain extent the economic impacts. The pollution results are presented in Table 32 and indicate that pollution generated from the entire economy is reduced slightly from the base case. Though the national impact is minimal, there is a reduction in pollutants due to decreased petroleum refining and iron and steel production, two of the major industrial polluters.

Communities with petroleum refining and steel plants will notice a degree of reduced pollution. However, if EPA regulations are enforced by 1985, the reduced emissions resulting from these lower production levels are unlikely to have a significant impact even on a local level. The reduction from pollution controls outweighs the reductions resulting from material substitutions.

SOLID WASTE MODULE

The impact on scrap availability can be seen in Figures 15 and 16 where scrap made available from iron and steel and from aluminum is plotted through 1995. Substantial increases in total available obsolete scrap are indicated for both cases. Aluminum scrap availability exhibits a proportionately greater increase than ferrous metals. However, the impact on solid waste is not felt until the late 1980's and early 1990's because of the time lag between production and actual disposal of the material into the waste system.

TABLE 32

COMPARISON OF POLLUTION RESIDUALS (%)
BETWEEN BASE CASE AND
MOST PROBABLE CAR

-1985-

	% Difference	
	Gross	Net
AIR POLLUTION		
1. Particulates		
Petroleum Refining	-10.0%	-10.0%
Steel	- 9.6%	- 9.2%
Aluminum	+ 7.4%	+ 6.9%
Total	- .71%	-1.22%
2. Sulphur Oxides		
Petroleum Refining	-10.0%	-10.0%
Steel	- 9.6%	- 9.7%
Total	- 2.8%	- 1.7%
3. Nitrogen Oxides	- .4%	- .38%
4. Hydrocarbons		
Petroleum Refining	-14.6%	-16.2%
Steel	- 9.6%	- 9.7%
Total	- 7.3%	- 1.4%
5. Carbon Monoxide		
Petroleum Refining	-10.0%	-10.0%
Steel	- 9.7%	- 9.7%
Total	- 3.7%	- .1%
WATER POLLUTION		
9. Biochemical Oxygen Demand	- .06%	- .16%
10. Chemical Oxygen Demand	- .10%	- .11%
12. Suspended Solids	- .1%	- .9%
17. Oil/Greases		
Petroleum Refining	-10.0%	-10.0%
Steel	- 9.7%	- 9.7%
Total	- 1.9%	- 9.5%
59. Phenols		
Petroleum Refining	-10.0%	-10.0%
Steel	- 9.7%	- 9.7%
Total	- 6.4%	- 4.0%

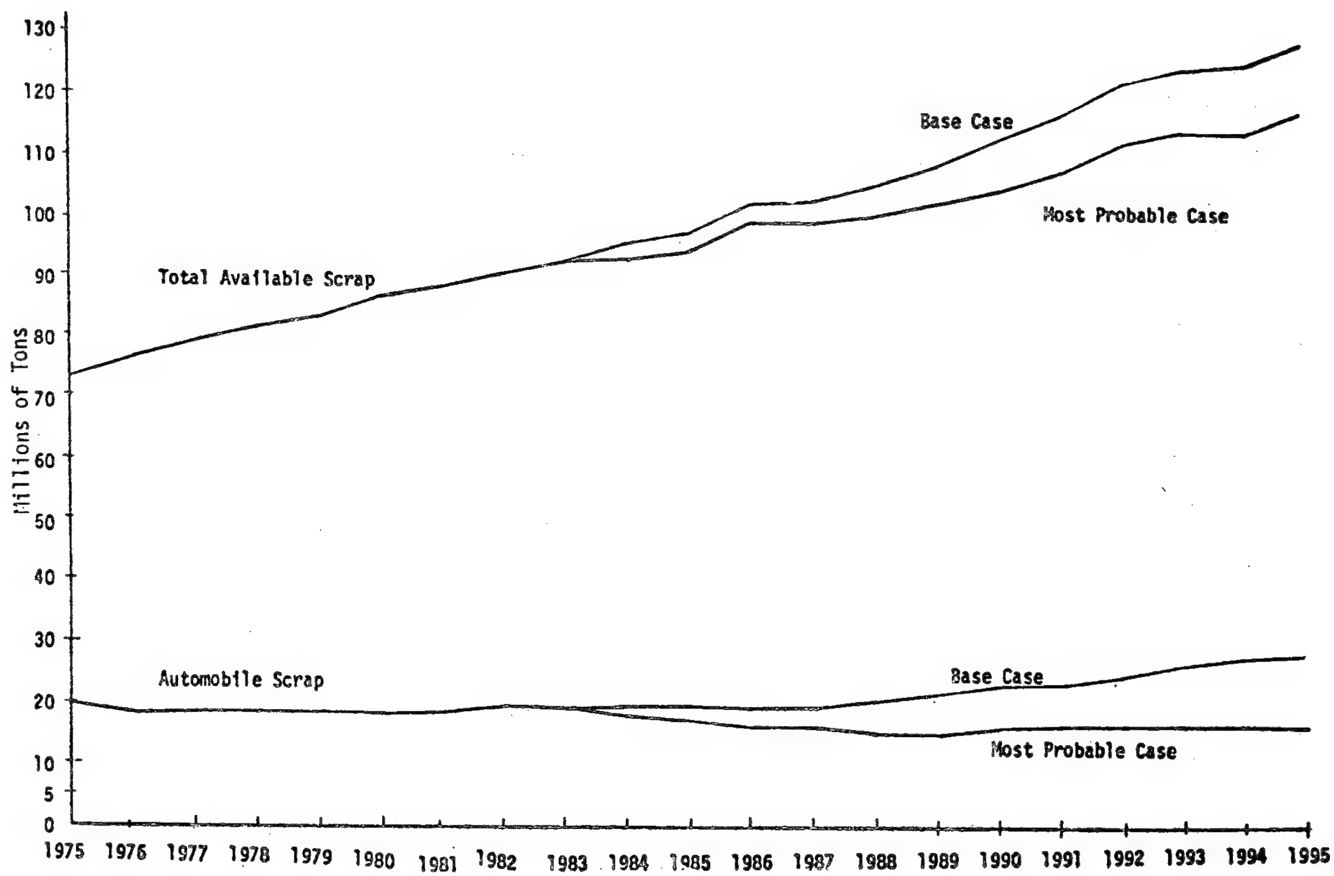


Figure 15. Projected Available Ferrous Scrap, 1975-1995
(Millions of Tons)

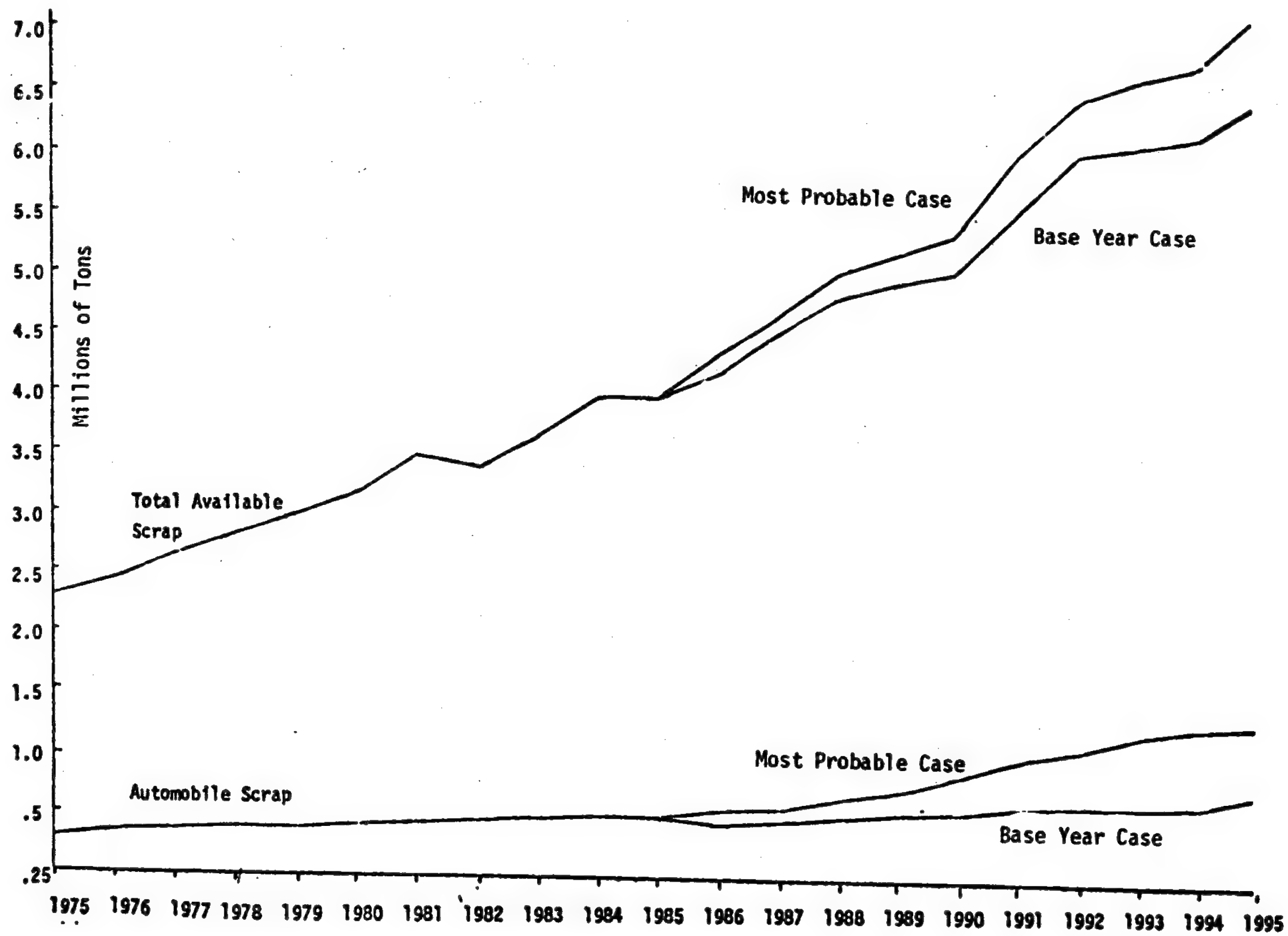


Figure 16. Projected Available Aluminum Scrap
(1975 - 1995)

There is approximately a 10% difference in total available iron and steel and aluminum scrap in each case by 1995. However, there is a significant impact on the availability of scrap derived from automobiles, with a 40% decline in iron and steel scrap from the base case and a greater than twofold increase in aluminum.

The critical question posed by the substitution of ferrous metals is whether or not a sufficient quantity of scrap will be available for the requirements of the iron and steel industry. Automobiles have traditionally supplied a major portion of obsolete scrap to be recycled as discussed in the previous part of this report and as projected in the SEAS solid waste module. The major constraints upon the use of nonautomotive sources of ferrous scrap have been economic, reflected in their scattered locations, high processing costs, and problems of contamination. Automobile scrap, available in units capable of being bundled or shredded and often brought to centralized disposal sites, has provided a good supply of scrap for the iron and steel industry. According to analysis done in this study independent of SEAS, the annual retirement of automobiles will not be sufficient by the mid-1980's to provide the scrap in the same proportion to what has been supplied in the past. This analysis is based on projected scrap requirements of the steel industry and capacity of the shredder industry assuming its present rate of growth.

Given this conclusion, the question arises whether or not other portions of the economy generate sufficient quantities of ferrous scrap capable of being recycled and thus fill the gap created by increased shredder capacity and demand for scrap by the iron and steel industry.

The solid waste model provides estimates of recycled material and assumes increases in the rate of recycling for various product categories. Based on the projected iron and steel furnace scrap requirements, total purchased scrap requirements would be 64.7

and 58.4 million tons in 1985 for each case as presented in Table 33. The solid waste model estimates that 58.6 and 54.3 million tons will be recycled in that year. Thus, a shortfall of 6.1 and 4.1 million tons is projected in each respective case assuming no scrap exports. With traditional export levels, the projected shortfall will be greater. It is interesting to note that the base case incurs a greater shortfall than the most probable because of projected higher scrap requirements for steel making. This projection agrees with the conclusion that ferrous scrap shortage is likely if recycling of nonautomotive products is not encouraged. Even though the solid waste model assumes some increases in recycling of nonautomotive products based on an optimistic industry projection, a shortfall occurs. Consumer durables (appliances) and industrial machinery may be considered as potential sources of concentrated scrap which could be economically recycled beyond the projections made in the solid waste model given a rise in scrap prices and assuming increased shredder capacity. Potential scrap from these sources is presented in Table 33 and is more than sufficient to cover the projected gap in scrap demand. This value does not include the backlog of presently discarded nonautomotive products.

The major conclusion of this analysis is that the ferrous scrap situation will be tight. Given increasing shredder capacity, scrap dealers may be driven into greater utilization of nonautomotive discarded products for sources of scrap. This situation would help to alleviate our national solid waste problem and may produce increased economic incentives to the resource recovery of municipal solid waste.

TABLE 33

IRON AND STEEL SCRAP REQUIREMENTS[a]
-1985-

	Base Case	Most Probable Case
Iron and Steel Output	153,884	139,045
Home Scrap at 35% of Total Production	82,861	74,870
Total Iron and Steel Production	236,945	213,915
Total Scrap Requirements	147,600	133,253
Home Scrap	82,861	74,870
Purchased Scrap Requirements	64,739	58,383
Prompt	26,320	23,782
Obsolete	38,419	34,601
Total Scrap Recycled	32,256	30,548
Shortfall	6,163	4,053
Potential Scrap from Household Durables and Machinery	8,846	8,846
Total Available Obsolete Scrap	95,845	93,820

[a]Scrap requirements for 1985 were computed based on the following projections for iron and steel furnaces:

	Production Level (%)	Scrap Requirements (%)
Basic Oxygen	55.9	33
Open Hearth	6.2	50
Electric Arc	26.0	98
Foundry	11.9	93

plus an additional estimate for the requirements of blast and miscellaneous furnaces. These levels were derived from estimates presented in Working Paper #6 and in Battelle's Identification of Opportunities for Increased Recycling of Ferrous Solid Waste, EPA, 1972. Other estimates were based on results in the Solid Waste/Recycling Model.

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